US006053946A

United States Patent [19]

Wilkinson

[11] **Patent Number: 6,053,946**

[45] **Date of Patent: Apr. 25, 2000**

[54] **FLEXIBLE PROSTHETIC FOOT APPARATUS**

[76] Inventor: **Kerry E. Wilkinson**, 5750 W. Linda La., Chandler, Ariz. 85226

[21] Appl. No.: **09/028,199**

[22] Filed: **Feb. 23, 1998**

[51] **Int. Cl.**[7] **A61F 2/66**

[52] **U.S. Cl.** **623/52**; 623/55

[58] **Field of Search** 623/47, 50, 52, 623/53, 55, 56

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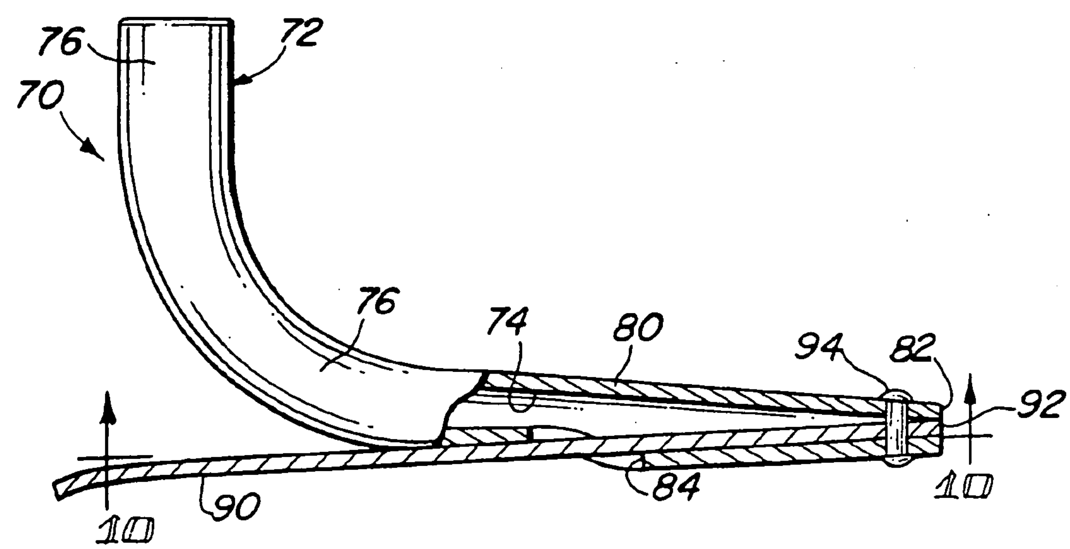
4,959,073	9/1990	Merlette	623/55
5,062,859	11/1991	Naeder .	
5,156,631	10/1992	Merlette .	
5,219,364	6/1993	Lloyd	623/33
5,258,039	11/1993	Goh .	
5,376,140	12/1994	Ryan .	
5,486,209	1/1996	Phillips .	
5,507,838	4/1996	Chen .	
5,549,714	8/1996	Phillips .	
5,593,456	1/1997	Merlette .	
5,593,457	1/1997	Phillips .	

Primary Examiner—David H. Willse
Attorney, Agent, or Firm—H. Gordon Shields

[57] **ABSTRACT**

Prosthetic foot apparatus includes a tubular element appropriately bent and flattened to provide desired flexibility. The extent of flexibility, and accordingly the extent of the bending and flattening of the tubular element provides desired stiffness or flexibility according to the desired characteristic, complementary of the user of the apparatus. Different embodiments are shown, including an embodiment which includes a separate foot plate secured to and extending into the foot portion of the tubular element.

5 Claims, 1 Drawing Sheet



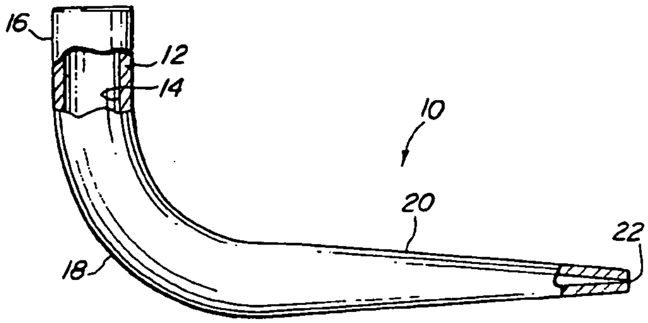


FIG. 1

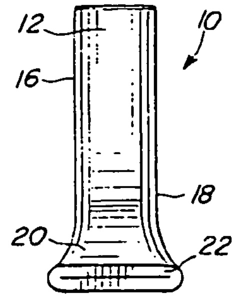


FIG. 2

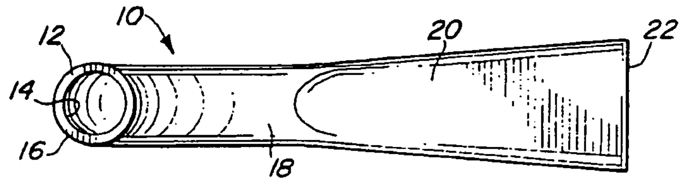


FIG. 3

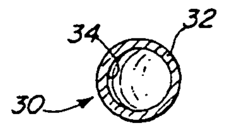


FIG. 5

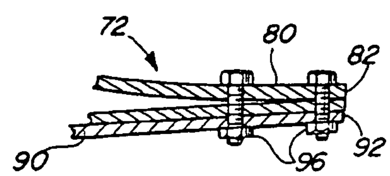


FIG. 11

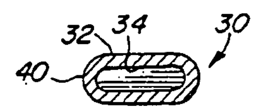


FIG. 6

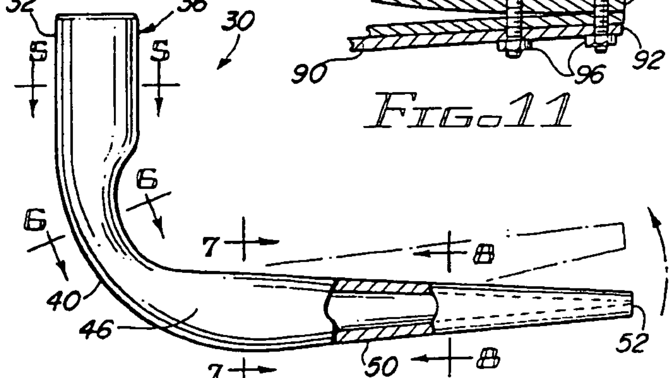
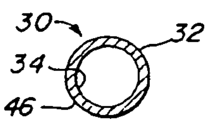


FIG. 4



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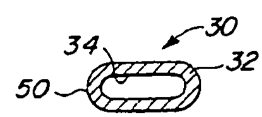

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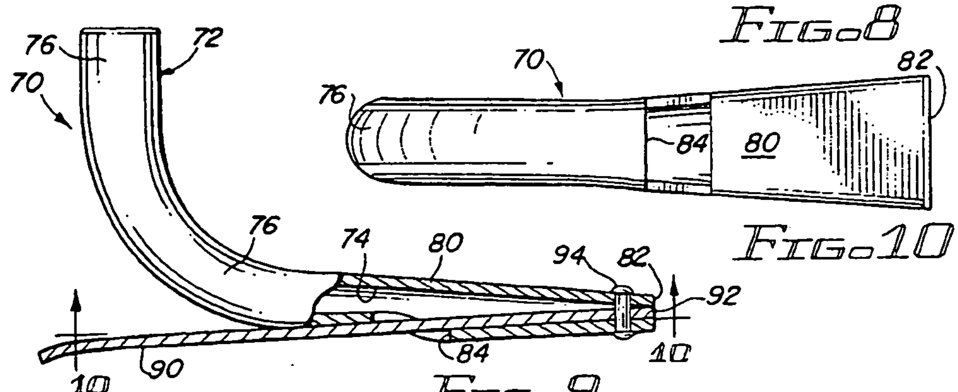

FIG. 9

FIG. 10

FLEXIBLE PROSTHETIC FOOT APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to prosthetic appliances and, more particularly, to a flexible prosthetic foot.

2. Description of the Prior Art

U.S. Pat. No. 4,547,913 (Phillips) relates to a composite prosthetic foot and leg which includes three portions, a leg portion, a foot portion, and a heel portion. The three portions are joined together rigidly. The three elements provide a degree of flexibility in response to ankle movements and foot movements, but provide sidewise rigidity. Various embodiments are disclosed.

U.S. Pat. No. 4,822,363 (Phillips) provides a different embodiment by the same inventor as the '913 patent, discussed above. The apparatus is made of laminated material to provide a prosthetic leg connected to a prosthetic foot. The leg portion is curved to define the foot, with a separate head portion connected to the foot portion. Various stiffness may be provided in the foot portion. Again different embodiments are disclosed.

U.S. Pat. No. 5,062,859 (Naeder) discloses a prosthetic foot which includes a resilient foot insert. The foot insert is of a general "Z" configuration. Different embodiments are illustrated.

U.S. Pat. No. 5,156,631 (Merlette) discloses a prosthetic foot and leg in which a leg element curves to define a foot element, and a separate segment is bonded to the forward extending foot portion extension of the leg element. The separate foot portion comprises or defines a sole element.

U.S. Pat. No. 5,258,039 (Goh et al) discloses a prosthetic foot apparatus made of resin impregnated woven fabric material. The apparatus is made of two segments both of which are curved to define a foot and heel portion and which provides the substantial degree of flexibility. Various embodiments or configurations are disclosed.

U.S. Pat. No. 5,376,140 (Ryan) discloses a prosthetic foot apparatus made of composite material. The apparatus has a general configuration of a natural foot with various elements involved, including a foamed polymer body, and cushioning material provides elasticity and flexion.

U.S. Pat. No. 5,486,209 (Phillips) discloses a prosthetic foot apparatus made of laminated materials. The apparatus includes an ankle portion, a foot portion, and a heel portion. Various configurations are illustrated.

U.S. Pat. No. 5,507,838 (Chen) discloses an artificial foot apparatus having a foot shaped casing and insert elements into the casing.

U.S. Pat. No. 5,549,714 (Phillips) discloses another prosthetic foot apparatus made of different elements secured together. Various elements are interchangeable to match the weight, stride, and activity schedule of the user of the apparatus.

U.S. Pat. No. 5,593,456 (Merlette) discloses another prosthetic leg and foot apparatus made of a single monolithic elongated composite member. The member includes a semi-flexible shank portion, an ankle portion, a fore-foot portion, and a toe portion. The apparatus is designed primarily for athletic type use.

U.S. Pat. No. 5,593,457 (Phillips) discloses apparatus similar to that disclosed in the above referred '290 patent. Both the '290 patent and the '457 patent are continuations of the same parent application.

SUMMARY OF THE INVENTION

The invention claims and described herein comprises a prosthetic foot made of a single tubular element which is flattened or configured to provide the degree of flexibility for the element. A second embodiment includes a flat plate appropriately secured to and extending inside of a foot portion of the tubular element.

Among the objects of the present invention are the following:

To provide new and useful prosthetic foot apparatus;

To provide new and useful prosthetic foot apparatus including a tubular element;

To provide new and useful prosthetic foot apparatus made of a tubular element and appropriately flattened or configured to provide a desired degree of flexibility;

To provide new and useful prosthetic foot apparatus including a flat plate secured to a tubular element; and

To provide new and useful prosthetic foot apparatus having a flat plate element secured to and extending into the interior of a foot portion of a tubular element.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a side view in partial section of the apparatus of the present invention.

FIG. 2 is a front view of the apparatus of FIG. 1.

FIG. 3 is a top view of the apparatus of FIGS. 1 and 2.

FIG. 4 is a side view of an alternate embodiment of the apparatus of FIGS. 1, 2, and 3.

FIG. 5 is a view in partial section taken generally along line 5—5 of FIG. 4.

FIG. 6 is a view in partial section taken generally along line 6—6 of FIG. 4.

FIG. 7 is a view in partial section taken generally along line 7—7 of FIG. 4.

FIG. 8 is a view in partial section taken generally along line 8—8 of FIG. 4.

FIG. 9 is a view in partial section of an alternate embodiment of the apparatus of the present invention.

FIG. 10 is a view in partial section taken generally along line 10—10 of FIG. 9.

FIG. 11 is a view in partial section of an alternate embodiment of FIGS. 9 and 10.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 is a side view of flexible prosthetic foot apparatus 10 of the present invention. FIG. 2 is a front view of the foot apparatus 10 of FIG. 1. FIG. 3 is a top view of the flexible foot apparatus 10 of FIGS. 1 and 2. For the following discussion, reference will be made to FIGS. 1, 2, and 3.

The flexible foot apparatus 10 comprises a tubular element 12 in which there is a bore 14. The foot apparatus 10 may be divided into three portions, an upper, straight portion 16, a curved, ankle portion 18, and a tapering lower portion 20. The lower portion tapers to a toe end 22 in which the tube 18 is substantially flat. The flattening of the tube 12 in the lower foot portion 20 results in an outward tapering of the lower foot portion 20, outwardly from the curved portion 18 to the end 22. This is best shown in FIG. 3.

In the side view of FIG. 1, the gradual tapering of the tube 12 from the upper straight or full diameter portion 16, through the curved portion 18, onto the foot portion 20, and

terminating in the toe end 22 is shown. The degree or extent of flexing varies according to the degree or extent of the flattening of the tube. In the embodiment of FIGS. 1–3, there will be some flexing in the curved portion 18, as an ankle flexing, but even more in the foot portion 20 and in the toe area 22.

FIG. 4 is a side view, partially broken away, of an alternate embodiment 30 of the apparatus 10 in FIGS. 1, 2, and 3. FIG. 5 is a view in partial section of the apparatus 30 taken generally along line 5—5 of FIG. 4. FIG. 6 is a view in partial section taken generally along line 6—6 of FIG. 4, while FIG. 7 is a view in partial section taken generally along line 7—7 of FIG. 4, and FIG. 8 is a view in partial section taken generally along line 8—8 of FIG. 4. For the following discussion, reference will be made to FIGS. 4, 5, 6, 7, and 8.

The flexible foot apparatus 30 is made of a tube 32 which has an interior bore 34. The flexible foot apparatus 30 includes a relatively straight upper portion 36, which corresponds to the upper portion 16 of the apparatus 10. The tubular member 32 includes a bore 34. The tubular member 32 is generally circular, and accordingly the bore 34 is generally circular.

Downwardly from the upper, straight portion 36 is a partially flattened or necked down curved portion 40. The portion 40 corresponds to an ankle portion of a natural leg in that there is flexing to a degree permitted in the area 40 by the flattening or necking down of the tube 32. The general flattening of the tube 32 in the area 40 is illustrated in detail in FIG. 6.

Downwardly from the neck down or flattened portion 40 is another circular or full cross-sectional area 46. In the area 46, the tubular member 30 is at a full diameter cross-sectional configuration, as illustrated in FIG. 7.

From the lower circular portion 46, the tubular member 32 tapers to an outer end 52. The tapering portion 50 is similar to the tapering front foot portion 20 of the apparatus 10. The tapering is accomplished by a gradual flattening of the tube 32 until the tubular member 32 is flattened to terminate at the end 52. The end 52, in an end view, is substantial the same as that illustrated in FIG. 2 for the end 22 of the tubular member 12.

In dash/dot line in FIG. 4, the flexing of the "ankle" portion 40 is illustrated. The dash/dot arrow adjacent to the tip 52 illustrates the relative movement of the foot tapering portion 50 relative to the upper straight portion 36. Again, the flexing is permitted or allowed by the necking down, or semi flattening of the tube 32 in the area 40, as illustrated in FIG. 6.

By varying the cross section of the tubular member 32 in the "ankle" portion 40, the flexing of the apparatus is varied. The greater the extent of the flattening or necking down, the greater the degree of flexing, and vice versa. Thus, in addition to the flexing of the portion 40, there will also be some flexing in the bottom foot portion 50 due to the flattening of the tubular member 32. This latter flexing provides a degree of springiness to the apparatus 30.

FIG. 9 comprises a side view in partial section of an alternate embodiment 70 of the apparatus of the present invention. The apparatus 70 is another alternate embodiment of the apparatus 10 of FIGS. 1, 2, and 3. FIG. 10 is a bottom view taken generally along ling 10—10 of FIG. 9. For the following discussion, reference will be made primarily to FIGS. 9 and 10.

The flexible prosthetic foot apparatus 70 is again made of a tubular member 72 which has a bore 74. The apparatus 70 includes an upper portion 76 which is generally straight, and accordingly the cross-sectional configuration of the tubular member 70 will be circular, such as illustrated in FIGS. 3, 5, and 7, for the apparatus 10 and 30. The straight upper portion 76 then curves to define a portion 76, which may be considered as an ankle portion. From the curved portion 76, the tubular member 72 is tapered inwardly and flattened and terminates in a front end or toe tip 82. The continual tapering of the flattening of the tubular member 72 from the upper straight portion 76 to the toe tip 82 may be understood from FIG. 9.

On the bottom of the tubular member 76, at the tapering foot portion 80, there is a slot 84. The front end of a plate 90 extends through the slot 84 and extends to the tip 82 where the plate terminates in an end 92. An appropriate fastener 94, such as a rivet, may be used to secure the plate 90 to the foot portion 80, if desired or if required. However, as shown in FIG. 9, and as also may be understood from FIG. 2 and from FIGS. 1 and 4, the end or tip 82 of the tubular member 76 is flattened so that the plate 90 is held relatively securely therein. Thus, at the front end of the foot portion 80, the tips 92 of the plate 90 and 82 of the tube 72 are flattened adjacent to each other.

The flattening of the tube 72 in the foot area 80, resulting from the inward taper of the tube 72, results in an outward taper of the portion 80, as best illustrated in FIG. 10.

FIG. 11 is a fragmentary view in partial section of an alternate embodiment of the apparatus 70 from that illustrated in FIG. 9. Instead of having the plate 90 extend through the slot 84 and into the interior bore 74 of the tubular member 72 at the foot portion 80, the plate 92 is simply appropriately secured to the bottom of the foot portion 80 by a pair of appropriate fasteners 96, such as nuts and bolts. This eliminates the need for the slot 84.

Three embodiments of a flexible prosthetic foot are illustrated and have been discussed. They all share in construction in that a tubular member is used to form the vertical portion of the foot and which is appropriately connected to a leg member or other prosthesis, not shown, but as is well known and understood. The tubular member curves to define an ankle portion between the vertical portion and a foot portion. Deformation of the ankle portion provides flexibility to create to a degree the desired movement. Flexing of the tubular member varies according to the flattening or deformation in the cross sectional configuration, as discussed above. The greater the extent of flattening of the tubular member, the greater the degree or extent of the flexibility.

While the principles of the invention have been made clear in illustrative embodiments, there will be immediately obvious to those skilled in the art many modifications of structure, arrangement, proportions, the elements, materials, and components used in the practice of the invention, and otherwise, which are particularly adapted to specific environments and operative requirements without departing from those principles. The appended claims are intended to cover and embrace any and all such modifications, within the limits only of the true spirit and scope of the invention.

What I claim is:

1. Prosthetic foot apparatus comprising in combination:

a resilient tubular prosthetic support element including
  a relatively straight upper tubular portion,
  a curved middle tubular portion,
  a lower tubular portion terminating in a relatively flattened end; and

the curved middle tubular portion is flattened to allow flexing of the tubular element.

2. The apparatus of claim 1 which further includes a plate secured to the lower tubular portion.

3. The apparatus of claim 2 in which the lower tubular portion includes a slot and the plate extends into the slot to secure the plate to the lower tubular portion.

4. The apparatus of claim 1 in which the flattening of the curved middle tubular portion is tapered to the lower tubular portion.

5. The apparatus of claim 4 in which the flattening of the curved middle tubular portion tapers on to the lower tubular portion.

* * * * *

US006206934B1

(12) United States Patent
Phillips

(10) Patent No.: **US 6,206,934 B1**
(45) Date of Patent: **Mar. 27, 2001**

(54) **ANKLE BLOCK WITH SPRING INSERTS**

(75) Inventor: **Van L. Phillips**, Rancho Santa Fe, CA (US)

(73) Assignee: **Flex-Foot, Inc.**, Aliso Viejo, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/138,357**

(22) Filed: **Aug. 21, 1998**

Related U.S. Application Data

(60) Provisional application No. 60/081,472, filed on Apr. 10, 1998.

(51) **Int. Cl.**[7] **A61F 2/66**

(52) **U.S. Cl.** **623/53**; 623/55; 623/47; 623/49

(58) **Field of Search** 623/47–55

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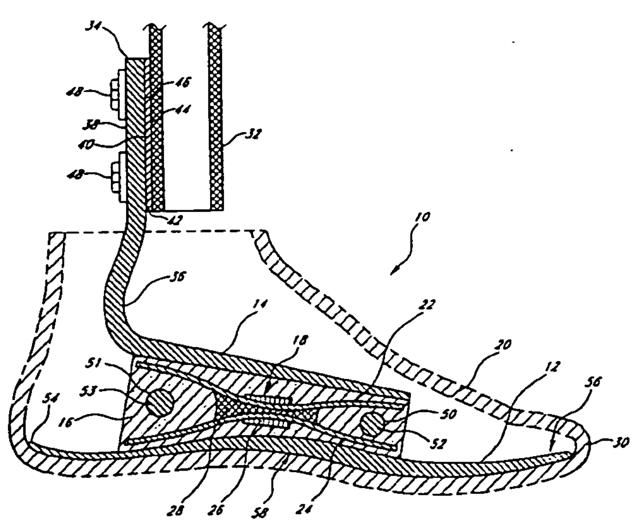
Primary Examiner—David H. Willse
Assistant Examiner—Suzette J. Jackson
(74) *Attorney, Agent, or Firm*—Knobbe, Martens, Olson & Bear, LLP

(57) **ABSTRACT**

Provided herein is a simple, inexpensive prosthetic foot incorporating an ankle block with spring inserts. The ankle block is formed of compressible material having desired compliance and energy return characteristics. The ankle block is sandwiched between a foot element and an ankle element. One or more spring inserts are embedded inside the ankle block to increase the rigidity of the prosthetic foot and to improve the degree of energy storage and return. The shape of the spring inserts is preferably one that supports compression during relative angular rotation of the ankle plate and foot plate elements, such as during toe and heel roll, and also vertical compression, such as in response to vertical shock loads.

52 Claims, 7 Drawing Sheets



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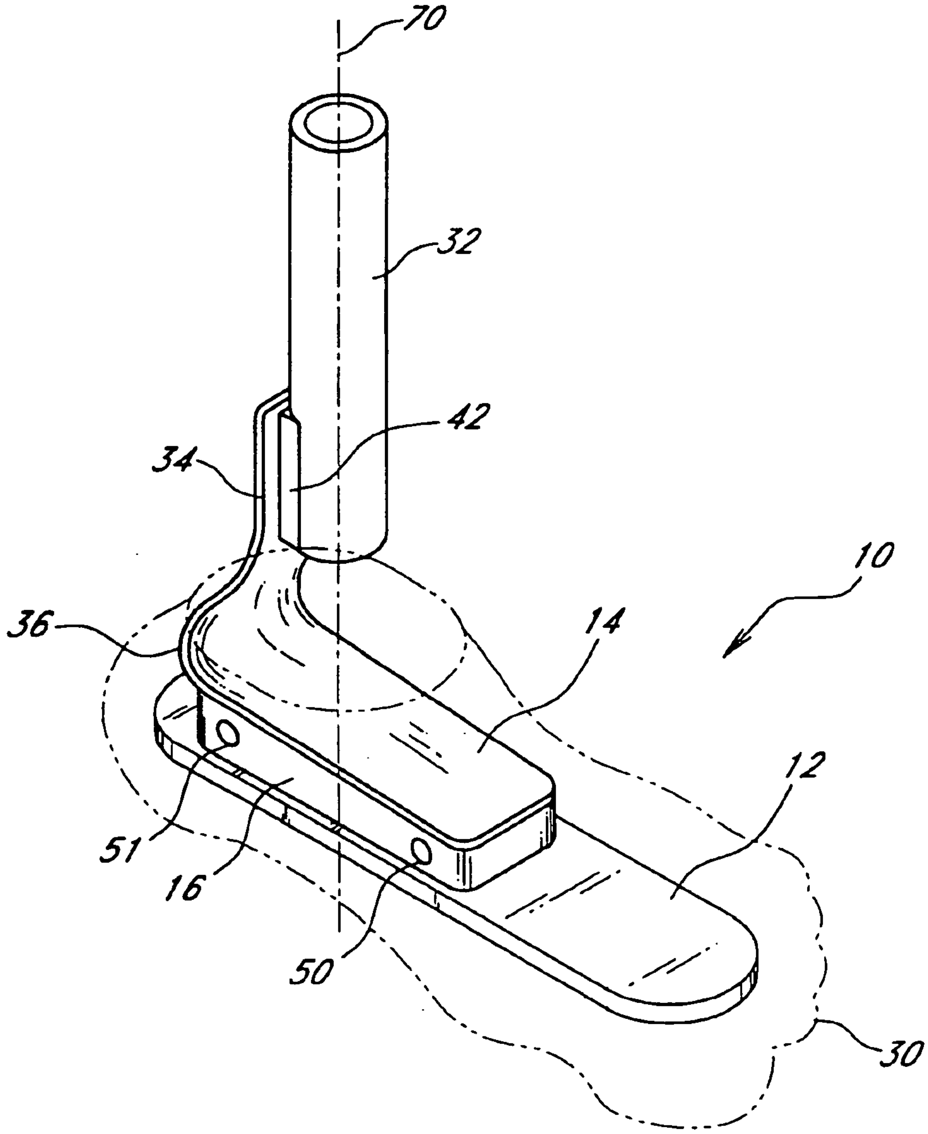
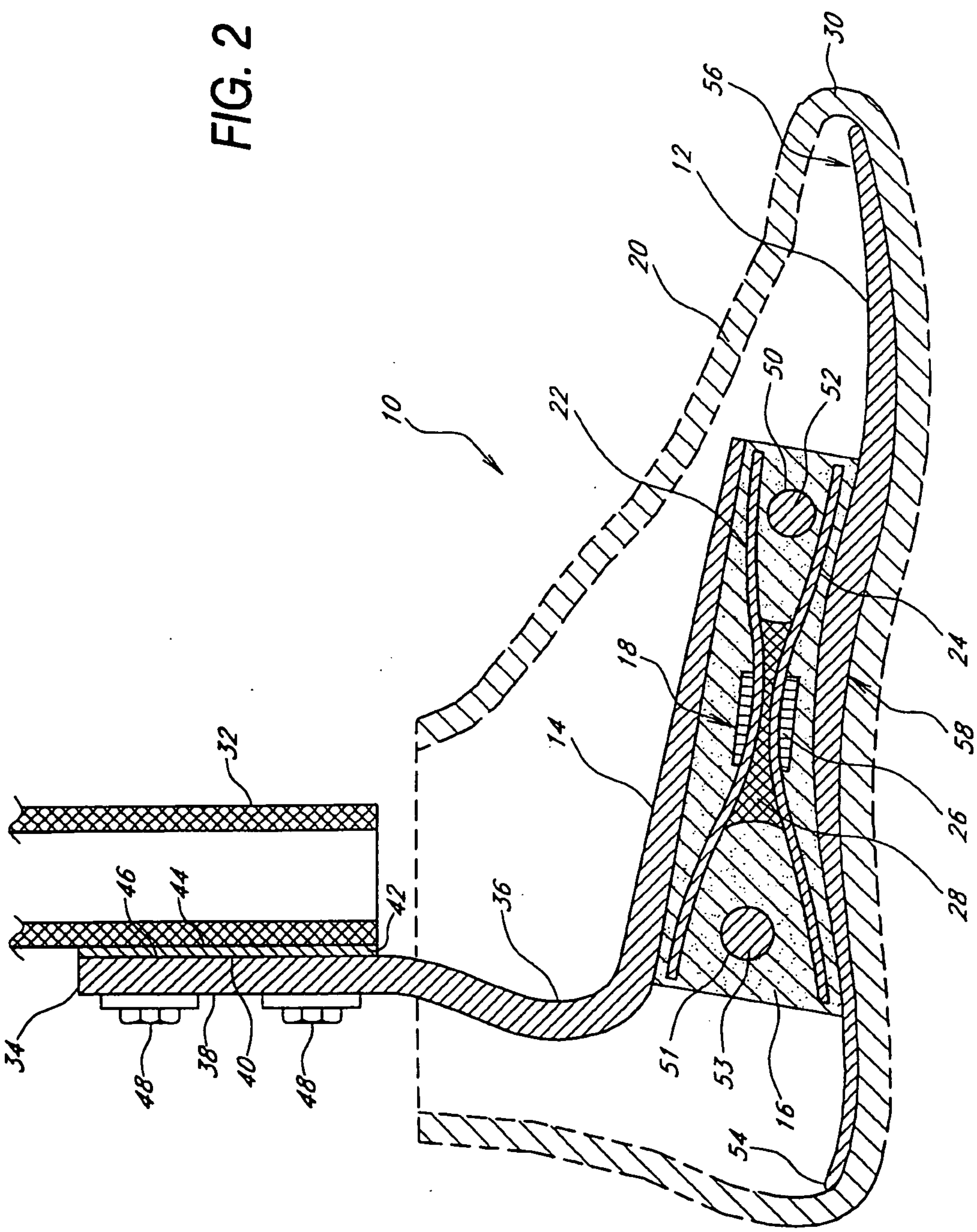


FIG. 1

FIG. 2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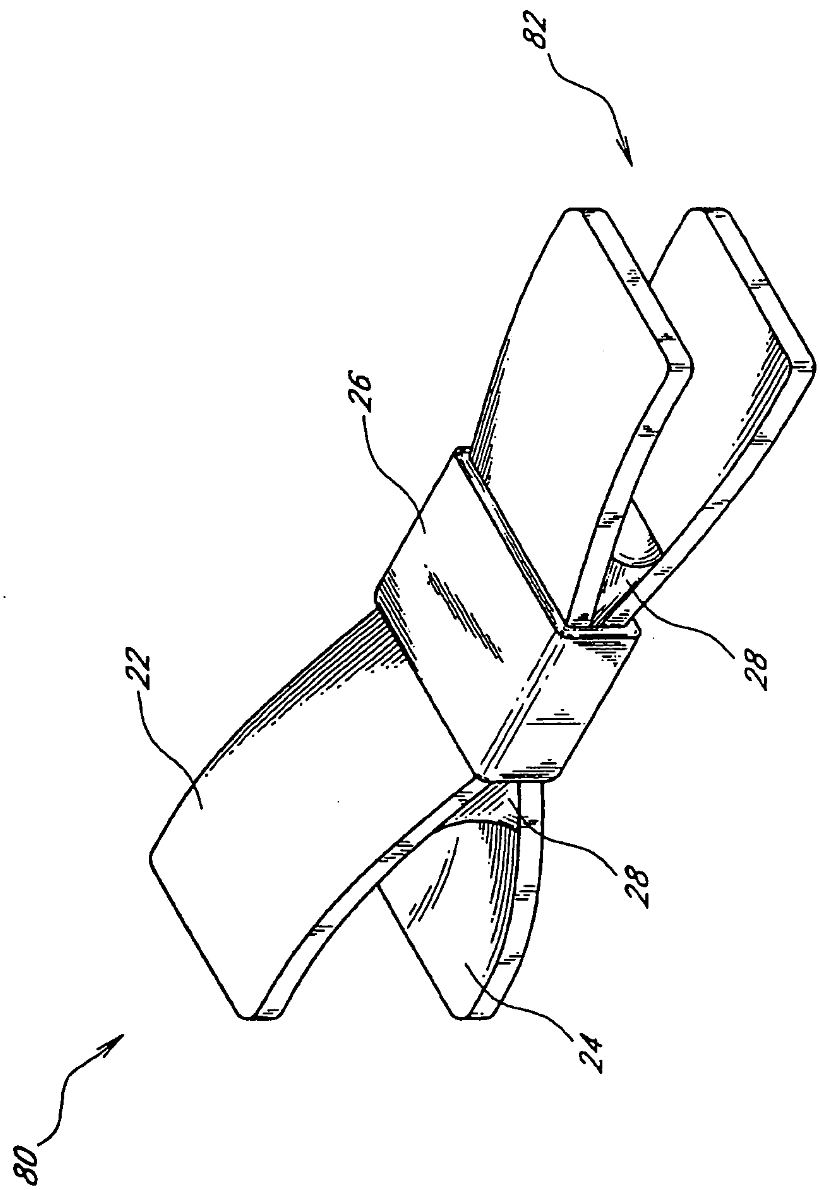

FIG. 3

FIG. 4

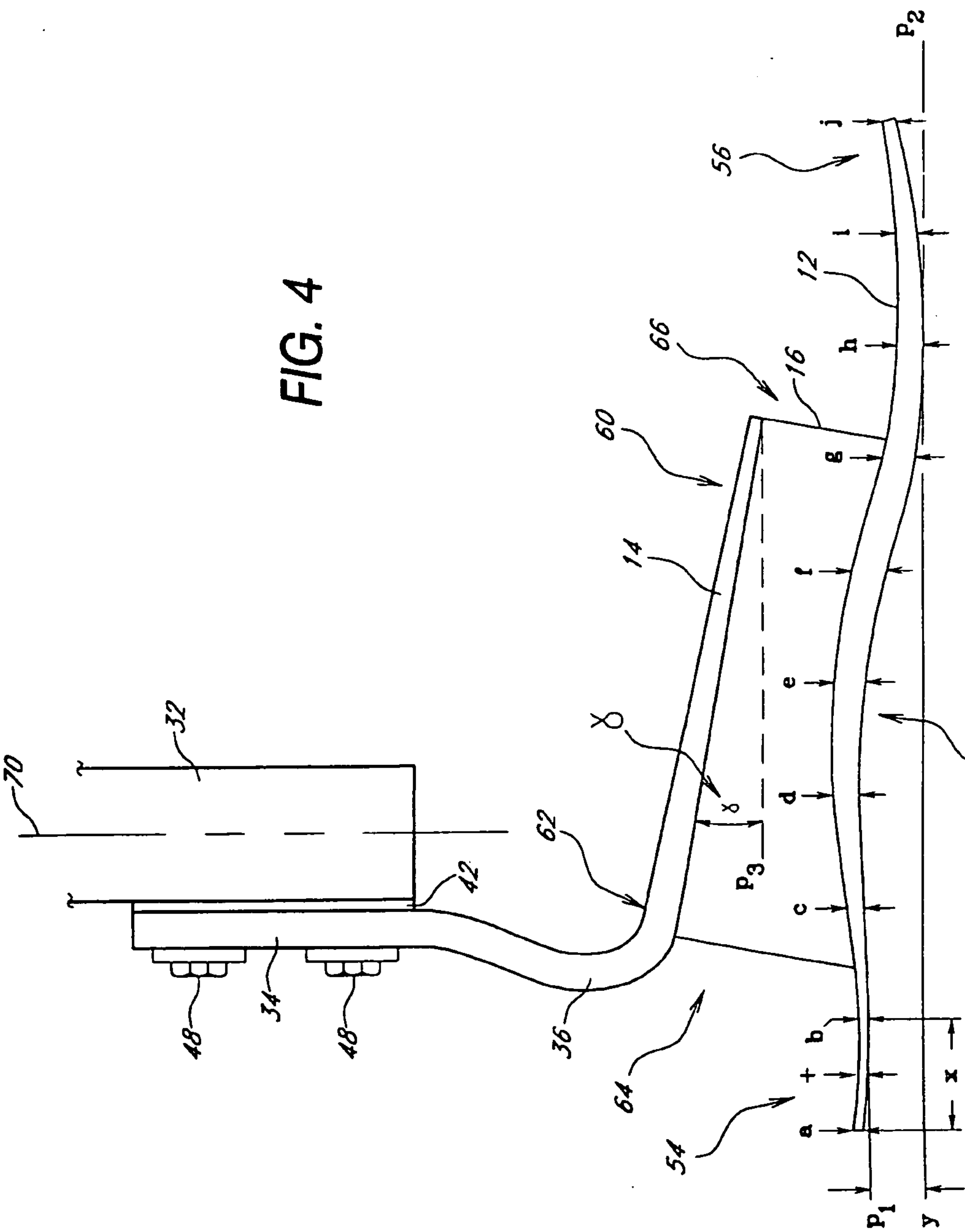
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FIG. 5A

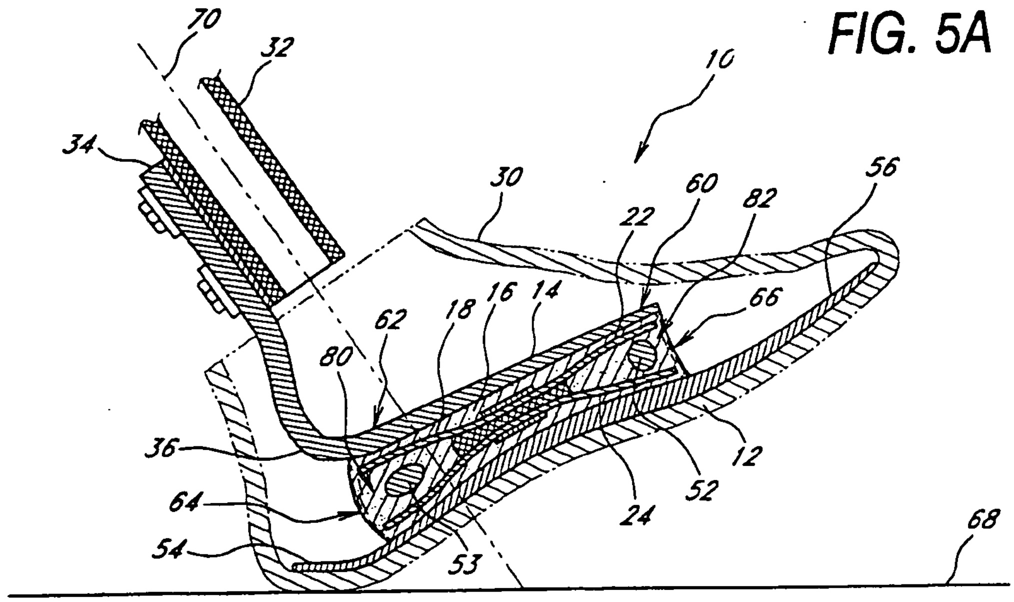
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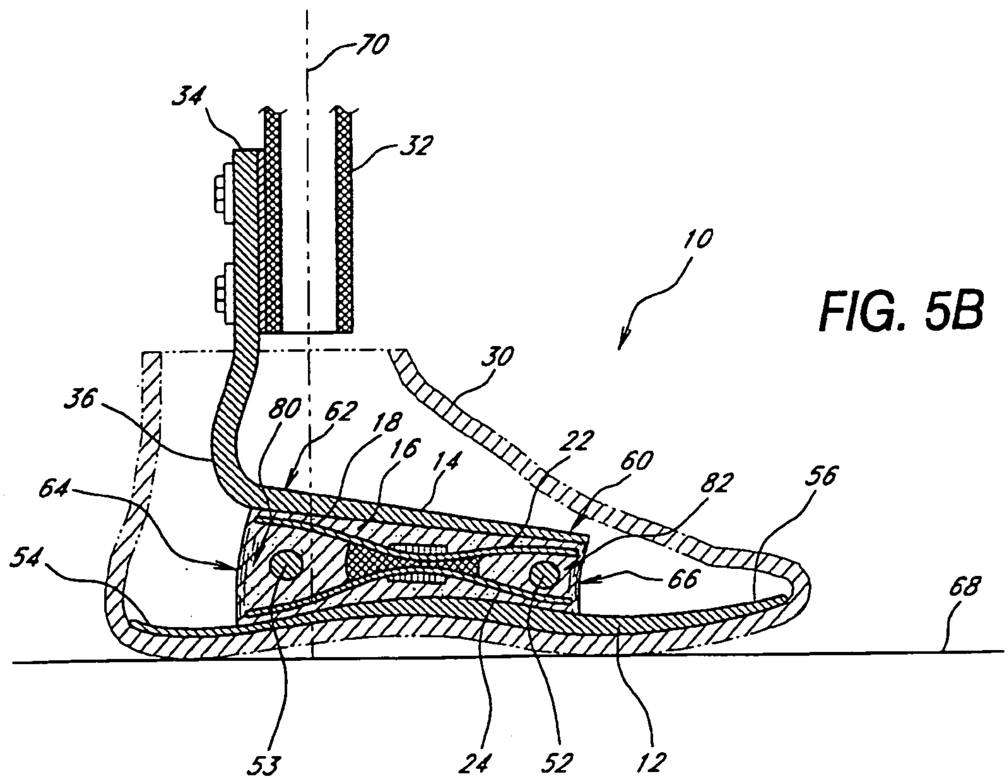
FIG. 5B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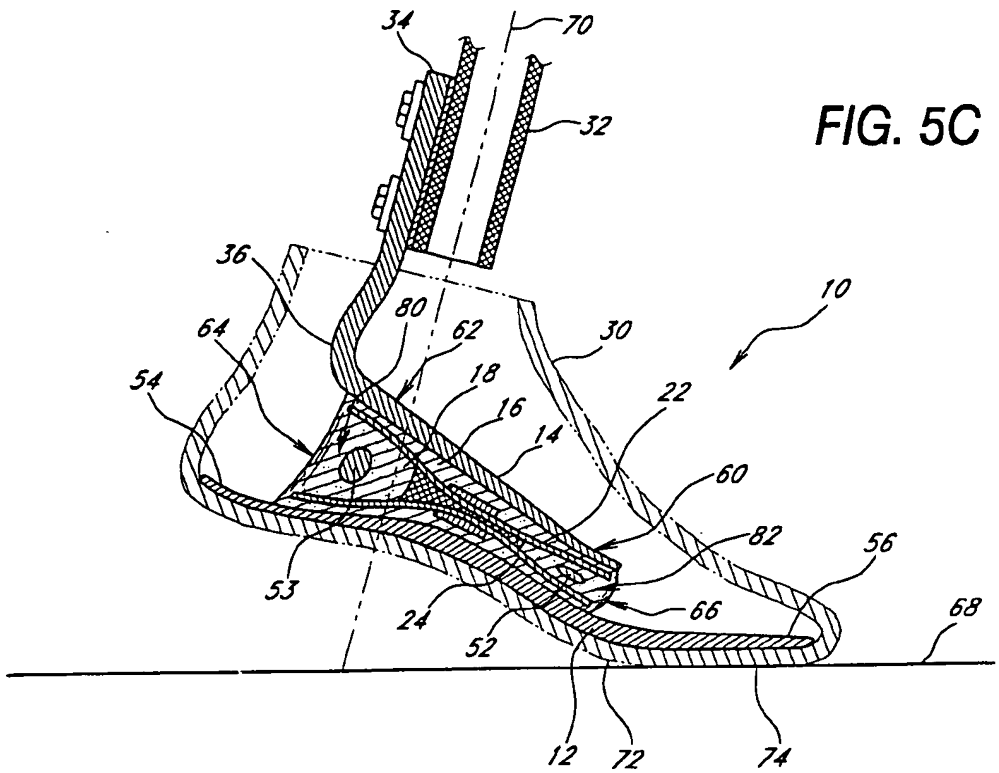
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FIG. 5C

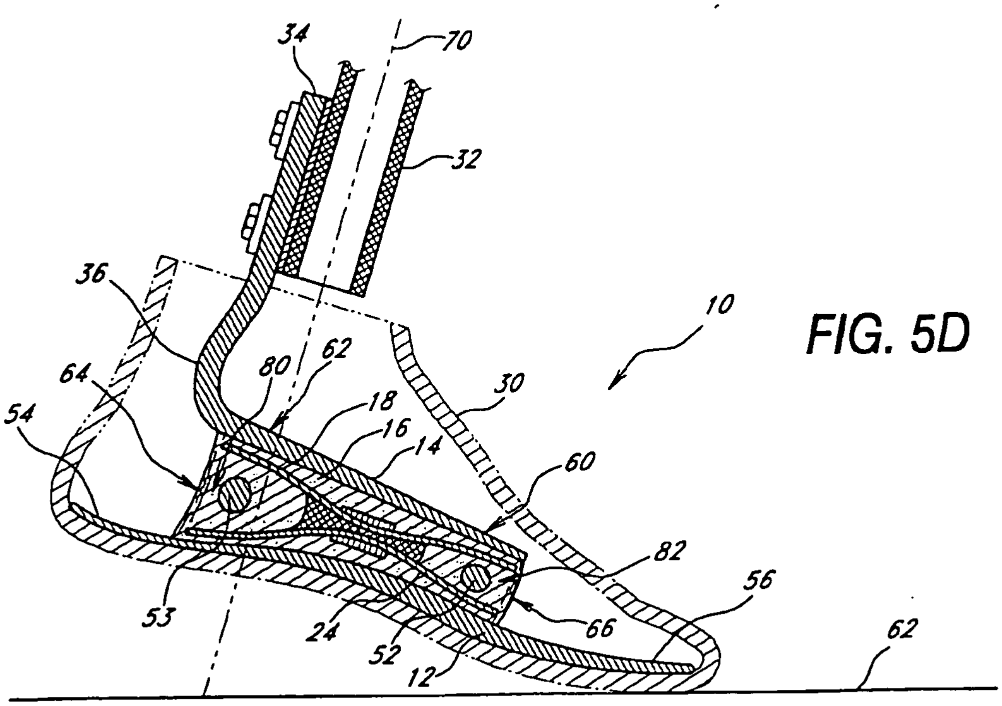
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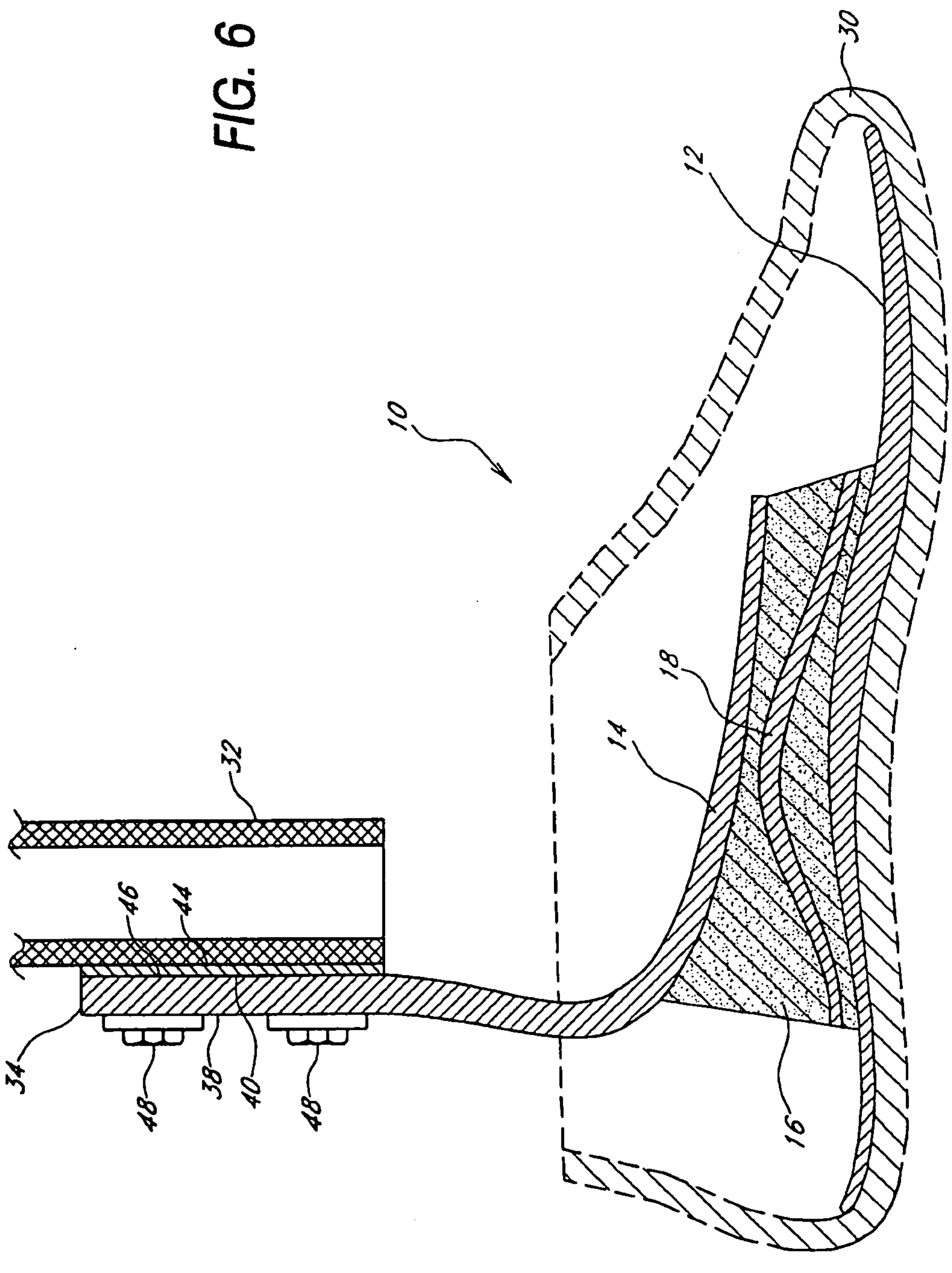
FIG. 5D

FIG. 6



ANKLE BLOCK WITH SPRING INSERTS

CROSS-REFERENCE TO PENDING APPLICATION

This application is a continuation of provisional application Ser. No. 60/081,472, filed Apr. 10, 1998.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to prosthetic feet and, more particularly, to a simply constructed, low-profile prosthetic foot having enhanced performance characteristics.

2. Description of the Related Art

In the prosthetics market, the conventional SACH (solid-ankle, cushion-heel) foot has been the most widely prescribed artificial foot over the past 35 years. The SACH foot generally includes a solid ankle and cushioned heel foot mounted to a limb along an approximate hinge axis taken through the ankle. The SACH foot has been popular precisely for its simplicity, and thus economy, but includes certain drawbacks in terms of dynamic response characteristics. Specifically, the low end SACH feet do not provide much energy storage and release, as do more sophisticated prosthetic feet.

Most modern foot prostheses incorporate some form of energy storage element for storing and releasing walking energy. Conventionally, this might consist of a spring-loaded ankle joint comprising metal coil springs or, more commonly, rubber compliance members. Inexpensive foot prostheses have also been devised having essentially a solid rubber or foam ankle block for storing and releasing walking energy. Such an ankle block has been disclosed in my issued patent titled PROSTHESIS WITH RESILIENT ANKLE BLOCK, U.S. Pat. No. 5,800,569, the entirety of which is incorporated by reference. A solid, compressible ankle block may be secured between upper and lower support members to provide resilient compression and energy storage and release. The use of an ankle block member provides significant manufacturing and cost advantages. However, for certain applications it is difficult to attain a desired level of spring compliance and energy return characteristics using a solid ankle block due to the inherent limitations of the materials involved in terms of elasticity, viscosity and maximum compression.

Therefore, it would be desirable to provide an ankle block having selectable compliance and energy return characteristics that may be varied over a wider range to accommodate the different weight, height and activity levels of amputees.

SUMMARY OF THE INVENTION

In response to the problems with the prior art, the present invention provides a simple, inexpensive prosthetic foot incorporating an ankle block with spring inserts. The ankle block is formed of compressible material having desired compliance and energy return characteristics. The ankle block is sandwiched between a foot element and an ankle element. One or more spring inserts are embedded inside the ankle block to increase the rigidity of the prosthetic foot and to improve the degree of energy storage and return. The shape of the spring inserts is preferably one that supports compression during relative angular rotation of the ankle plate and foot plate elements, such as during toe and heel roll, and also vertical compression, such as in response to vertical shock loads.

In one aspect of the present invention, a basic prosthetic foot is provided having enhanced performance characteristics generally comprising a lower foot plate, an upper ankle plate, a foam ankle block joining the two plates, and a spring element embedded in the ankle block. Both the foot plate and the ankle plate are constructed of strong, flexible material, preferably a laminate of composite material. The foot plate is sized approximately equal to a human foot being replaced, while the ankle plate has a similar width, but has a shorter length than the foot plate. The ankle block has a length and width approximately equal to the ankle plate and is aligned therewith. The spring element comprises two relatively flat carbon fiber composite members secured at their middle and separated at their ends. This gives the spring element a preferable shape of a bowtie or double wishbone. Preferably, an attachment member couples the ankle plate to a stump or lower-limb pylon of the wearer. During walking, the combination of the resilient ankle block with embedded spring element and flexible plates provides a smooth rollover from a heel-strike to a toe-off position.

In another aspect, the ankle block of a prosthetic foot may be provided with cylindrical openings both in the fore and aft positions of the ankle block. These openings enable the placement of additional inserts or stiffeners to give the block a desired rigidity. In a preferred embodiment, the foot element also has a tapered thickness. Further, the foot element comprises uplifted heel and toe ends and an arch region therebetween.

Further advantages and applications will become apparent to those skilled in the art from the following detailed description and the drawings referenced herein.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of the prosthetic foot of the present invention.

FIG. 2 is a cross-sectional view of the prosthetic foot of the present invention.

FIG. 3 is a perspective view of the spring element embedded in the ankle block of the present invention.

FIG. 4 is a side elevational view of the prosthetic foot more clearly showing a foot plate having a tapered thickness along its length.

FIG. 5A is a sectional view of the prosthetic foot in a heel-strike position of a walking stride.

FIG. 5B is a sectional view of the prosthetic foot in a flat position of a walking stride.

FIG. 5C is a sectional view of the prosthetic foot in a heel-off position of a walking stride.

FIG. 5D is a sectional view of the prosthetic foot in a toe-off position of a walking stride.

FIG. 6 is a cross-sectional view of an alternative embodiment of the prosthetic foot of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

With reference to FIGS. 1 and 2, a first embodiment of a prosthetic foot 10 of the present invention is shown in a perspective view and a cross-sectional side view, respectively. The prosthetic foot 10 generally comprises a lower foot plate 12 an upper, smaller ankle plate 14, an ankle layer or block 16 made of resilient material, connecting the foot plate 12 to the ankle plate 14, and a spring element 18 embedded within the ankle block 16. The foot plate 12 has a length and width roughly equal to the approximate length and width of the particular wearer's amputated foot and sized to fit within an outer, flexible cosmesis 30, shown in

phantom. The ankle plate 14 and the resilient ankle block 16 have approximately the same horizontal cross-sectional size. The ankle plate 14, ankle block 16, and spring element 18 are centered transversely with respect to and are generally positioned over the back half of the foot plate 12. The ankle block 16 is sandwiched between the foot plate 12 and the ankle plate 14 and is preferably glued or bonded to both plates using polyurethane adhesive or other known securement technologies.

The spring element 18 is a resilient support member inserted within the resilient ankle block 16. As shown in FIG. 3, the spring element 18 is preferably comprised of upper and lower plate-like members 22 and 24, each of which is relatively flat and has a substantially rectangular vertical projection. These members are secured at their center by a fastener 26 and separated at ends 80 and 82. The upper member 22 preferably has a curvilinear concave upward shape, while the lower member 24 preferably has a curvilinear concave downward shape. This gives the spring element 18 a substantially double wishbone or bowtie shape.

As shown in FIG. 1, the spring element 18 is completely embedded within the ankle block 16 so as not to be visible from the outside. Referring to FIG. 2, the spring element 18 extends substantially longitudinally across the length of the ankle block 16, and has a width substantially equal to the width of ankle block 16. The fastener 26 may comprise bolts, a weld, or any other fastening means as would be known to those skilled in the art. In the preferred embodiment, the fastener 26 is a strap which is laminated around the center portion of the two members 22, 24. A wedge member 28, preferably of a resilient elastomer, is placed between the two plate members 22, 24 to protect the inner surfaces of the members and to provide additional support to the spring element 18. The wedge 28 acts to provide leverage between the two plate members 22, 24, and enables adjustment of the flexing characteristics of the spring element 18, if desired. Alternatively, it may be bonded permanently in place or formed integrally with one or both of the plate members 22, 24, as desired. Although the spring element 18 has been described as having a double wishbone or bowtie configuration, other shapes and sizes may be appropriate for providing support to the ankle block 16. Furthermore, more than one spring element may be provided in the ankle block to provide support and energy return to the prosthetic foot 10.

As can be seen in FIGS. 1 and 2, the prosthetic foot 10 further comprises a pylon member 32 which can be secured to the stump of the amputee (not shown) and extends relatively downward therefrom in a generally vertical direction. The pylon member 32 in the preferred embodiment is of tubular construction having a substantially equal moment of inertia in all directions to restrict bending in all directions. The tubular member 32 is also preferably hollow so that it is relatively light in weight and utilizes less material which reduces the cost of production. The pylon member 32 is dimensioned so as to be interchangeable with a standard 30 mm pylon. Other configurations which impart rigidity, such as rectilinear cross sections having relatively larger moments of inertia about one or both transverse axes can also be utilized to obtain the benefits discussed herein. A centerline 70 through pylon 32, shown in FIG. 1, defines the downward direction of the application of force.

As shown in FIGS. 1 and 2, the ankle plate 14 is secured to the pylon member 32 through a vertically oriented upper attachment member 34. The upper attachment member 34 is attached to a curvilinear ankle section 36, which is connected to the ankle plate 14. Preferably, these three pieces are monolithically formed with one another for optimum strength and durability. The attachment member 34 has a rearward surface 38, as shown in FIG. 2, and a forward surface 40 substantially parallel thereto. The attachment member 34 is substantially rigid and capable of sustaining torsional, impact and other loads impressed thereupon by the prosthesis. In addition, the inherent rigidity of attachment member 34 prevents it from being distorted in any substantial way and causes the effective transmission of the aforesaid loads imposed thereupon to a suitable ancillary prosthetic pylon 32.

With reference to FIG. 2, the attachment member 34 is in the preferred embodiment vertically oriented so that it may be secured to the pylon member 32. A coupling device 42 is positioned at the lower end of the pylon member 32 which provides a flat surface upon which the vertical attachment member 34 can be secured. The coupling device 42 has one attachment surface 44 which mates with the cylindrical outer surface of the pylon member 32 and a second substantially flat attachment surface 46 which mates with the attachment member 34. In the preferred embodiment, attachment surface 44 is curved to closely mate with the outer surface of the tubular pylon member 32, and attachment surface 46 is flat to accommodate the forward surface 40 of the attachment member 34.

Desirably, the coupling device 42 is welded or bonded to the pylon member 32 and has two holes (not shown) into which two bolts 48 can be inserted and secured. The attachment member 34 also has two holes (not shown) which align with the holes on the coupling device to place and secure the two bolts 48 through the attachment member 34 and the coupling device 42. Other methods of securing the pylon member to the foot portion are contemplated, such as those disclosed in my prior issued U.S. Pat. No. 5,514,186, the entirety of which is incorporated by reference, as well as those utilizing integrally formed constructions.

As stated, the attachment member 34 monolithically formed with the ankle plate 14 is vertically aligned so that it extends relatively downward from the coupling device 42 on the pylon member 32. As shown in FIG. 2, the thickness of the attachment member 34 along this vertical section is relatively greater than the thickness of the ankle plate 14 substantially horizontally aligned along the foot portion. The attachment member 34 is also made relatively thicker to support the vertical load imposed on the prosthetic device as well as to restrict undue bending at this juncture. The entire upper vertically-aligned section of attachment member 34 is preferably of substantially uniform thickness and width.

The tubular pylon member 32 is preferably removable from the prosthetic device such that the pylon member can be replaced without replacing the remainder of the prosthetic device. This permits Applicant's invention to be utilized in a broader range of applications. For instance, the tubular member of Applicant's invention can be cut and adapted for use by amputees having different stump lengths including growing amputees. The prosthetist merely needs to cut a standard tubular pylon to the appropriate length. Moreover, this eliminates the need to manufacture as a part of the prosthesis a long rigid leg section. Thus, fewer materials are needed to manufacture the prosthesis of Applicant's invention resulting in reduced manufacturing costs.

The preferred embodiment further comprises cylindrical slots or openings 50, 51 in the fore and aft portions of the ankle block 16, respectively, as shown in FIG. 2, to accommodate insertion of stiffeners 52, 53. The cylindrical openings 50, 51 are disposed horizontally in a direction generally

transverse to a forward walking motion, and between upper and lower plate members 22 and 24. Stiffeners 52, 53 can be removably placed in these openings to provide additional support and rigidity to the prosthetic foot 10, and also to modify the spring characteristics of the prosthetic foot. For instance, additional energy storage and return can be provided for a more active amputee by inserting stiffeners 52, 53 into ankle block 16 having a higher spring constant. On the other hand, when more control is desired, stiffeners with a lower spring constant may be inserted to produce an ankle block 16 with greater dampening characteristics. Alternatively, the cylindrical openings 50, 51 may remain empty, thereby making the compliance characteristics dependent solely on the ankle block 16 and the spring element 18.

Preferred Materials and Fabrication

Both the foot plate 12 and the ankle plate 14 are preferably formed of a flexible material so that flexing of the plates tends to relieve extreme shear stresses applied to the interfaces between the ankle block 16 and the plates 12, 14. Both the foot plate 12 and the ankle plate 14 are preferably constructed of fiberglass which provides strength and flexibility. The preferred material for the ankle plate 14 and the foot plate 12 is a vinyl ester based sheet molding compound, such as Quantum #QC-8800, available from Quantum Composites of Midland, Mich. Alternatively, the plates may be formed by a plurality of lamina embedded in an hardened flexible polymer. In other arrangements, the plates may be formed of other materials such as carbon fiber composites as may be apparent to one skilled in the art. The desirable properties of the plates are that they are relatively resilient so as to withstand cracking upon application of repeated bending stresses yet have sufficient flexibility to enhance the performance characteristics felt by the wearer in conjunction with the properties of the resilient ankle block. The pylon member 32 is preferably made of a stiff material such as a laminate of fiber reinforced composite. Stiffness in the pylon member 32 can also be provided by a stiffer and more dense material.

The ankle block 16 is sandwiched between the foot plate 12 and the ankle plate 14 as shown in FIGS. 1 and 2 and is preferably bonded to both plates. The ankle block is preferably formed of urethane, rubber or other suitable material having desired compliance and energy return characteristics. A preferred material for the ankle block is expanded polyurethane foam such as cellular Vulkolka® Pur-Cell No. 15-50, with a density of approximately 500 kg/m^3 as available from Pleiger Plastics Company of Washington, Pa. Alternatively, the ankle block 16 may be molded or fabricated from a wide variety of other resilient materials as desired, such as natural or synthetic rubber, plastics, honeycomb structures or other materials. Cellular foam, however, provides a high level of compressibility with desirable viscoelastic springiness for a more natural feeling stride without the stiffness drawbacks and limited compression associated with solid elastomeric materials. Furthermore, the cellular nature of a foam block makes it lighter than solid elastomers. Foam densities between about 150 and 1500 kg/m^3 may be used to obtain the benefits of the invention taught herein.

The spring element 18 is preferably made from a highly resilient material that is capable of supporting compression during relative angular rotation of the upper and lower members 12 and 14, such as during toe and heel roll, and also vertical compression such as in response to vertical shock loads. One preferred material is carbon fiber composites such as woven fiber mats and chopped fiber in an epoxy matrix. However, other materials with similar strength and weight characteristics will be known to those skilled in the art and may be used with efficacy. For instance, other filament types may be used, such as glass, Kevlar and nylon by way of example, to ensure lightweight and structural and dynamic characteristics consistent with the needs of a particular amputee. The wedge 28 may be fabricated from a wide variety of resilient materials, including natural and synthetic rubber, elastomeric polyurethanes, or the like.

The ankle block 16 containing spring element 18 may be fabricated by injecting a polyurethane elastomer into a mold allowing it to cure. The spring element 18 may be inserted into the mold prior to injection of the polyurethane so that during curing, the polyurethane bonds to the spring member. Cylindrical slots or openings 50, 51 for insertion of stiffeners 52, 53 may be provided in ankle block 16 by inserting cylindrical plugs into the block prior to injection of polyurethane. Alternatively, openings may be provided in the block after curing simply by cutting or drilling away portions of the ankle block.

The stiffeners provided in the openings are preferably tubes of foam material having a density chosen according to desired compliance characteristics. A preferable material is expanded polyurethane having a foam density between about 150 and 1500 kg/m^3. More preferably, a density of about 250 to 750 kg/m^3 is preferred to provide adequate adjustment of the energy storage and return characteristics of the prosthetic foot.

Preferred Dimensions

As illustrated in FIG. 4, the foot plate 12 is preferably of curvilinear shape. The thickness t of foot plate 12 is preferably tapered along its length, and the tapered profile corresponds approximately to the weight of the amputee. That is, for a heavier amputee, the thicknesses along the length would be greater than for a lighter weight amputee. Generally, the weight groups may be classified as light, medium, or heavy.

Table I below presents preferred groupings, as module sizes C/D/E, of cosmesis sizes corresponding to a male "A" width shoe last. The sizes are presented by length L, width B at the forefoot and width H at the heel of the cosmesis.

TABLE I

Cosmesis Sizes for Male "A" Width Shoe Last

MODULE	LENGTH L (cm)	WIDTH B (cm)	WIDTH H (cm)
C	22	2.88	2.19
	23	3.00	2.25
	24	3.12	2.31
D	25	3.25	2.44
	26	3.38	2.50
	27	3.50	2.56
E	28	3.62	2.69
	29	3.75	2.75
	30	3.88	2.81

Table II below presents preferred module sizes for various weight groups of amputees.

TABLE II

Modules vs. Weight Groups

MODULE	WEIGHT GROUP LIGHT	MEDIUM	HEAVY
C	CL	CM	—
D	DL	DM	DH
E	—	EM	EH

Table III below presents preferred taper thicknesses (t) for an average or "DM" size foot plate 12 taken at positions spaced by distance x=1 inch (2.54 cm).

TABLE III

Taper Thickness t for DM Foot Plate

POSITION (x = 2.54 cm)	THICKNESS t (cm)
a	0.16
b	0.16
c	0.32
d	0.52
e	0.69
f	0.78
g	0.71
h	0.60
i	0.48
j	0.28

The foot plate 12 has a heel end 54, toward the left in FIG. 4, which is concave-upward or slightly uplifted from a horizontal plane P_1 tangential to the heel end 54 of the foot plate 12. Similarly, a toe end 56, to the right of FIG. 4, is concave upward or somewhat uplifted from a horizontal plane P_2 tangential to the front portion of the foot plate 12. An arch section 58 is formed between the heel and toe ends and is preferably concave-downward, as shown.

It is understood that within the cosmesis 30 (not shown), the tangent plane P_1 of the heel end 54 is slightly raised a distance y relative to the tangent plane P_2 of the toe end 56, as shown. The DM-sized foot plate of Table III, for example, has y=0.5 inches (1.27 cm). The foot plate 12 is preferably 0.25 inches (0.63 cm) from the bottom or sole of the cosmesis 30. The cosmesis 30 may be insert molded using an anatomically sculpted foot shape, with details and sizing based on a master pattern and/or digitized data representing typical foot sizes.

An intermediate region 58 comprising the arch portion of the foot plate 12 has the greatest thickness of the foot plate 12. The curvature of the arch region 58 is defined by the cosmesis or shoe sole profile, and generally corresponds to selected ranges of human foot lengths.

The foot plate 12 of prosthesis 10 preferably has a length between about 5 and 15 inches (about 13 and 38 cm), more preferably between about 8 and 12 inches (about 20 and 30 cm) for the foot sizes given in Table I. The width of foot plate 12 is preferably about 1 to 4 inches (about 2.5 to 8 cm). For the example given in Table III for a DM-sized foot plate 12 the length of the plate 12 is approximately 9 inches (about 23 cm) and its width is about 2 inches (about 5 cm). The foot plate 12 has a thickness between about 0.05 and 0.4 inches (about 0.1 and 1 cm), which more preferably may be tapered as indicated in Table III.

The ankle plate 14 of prosthesis 10 is substantially planar, and is preferably shorter in length than the foot plate 12 and has a thickness also defined by the weight group of the wearer. The thickness of the ankle plate is preferably about 0.05 to 0.4 inches (0.1 to 1 cm). More preferably, the corresponding ankle plate 14 in the present example is about 0.2 inches (about 0.5 cm) thick at rear portion 62, tapering to a thickness of about 0.1 inches (about 0.25 cm) at front portion 60. The ankle plate 14 preferably has a length of about 3 to 7 inches (about 8 to 18 cm) and a width of about 1 to 3 inches (about 2.5 to 8 cm), more preferably having length-width dimension of approximately 5×2 inches (about 13×5 cm). The ankle plate 14 is positioned at an angle such that its front tip 60 is located closer to the foot plate 12 than its rear tip 68. Relative to plane P_3 shown in FIG. 4, the rear tip is preferably raised an angle γ of about 5 to 30 degrees, and more preferably, about 10 degrees.

The ankle block 16 is generally sized such that its upper surface is planar and corresponds to the length and width of the ankle plate 14. The lower surface of the ankle block 16 is substantially curvilinear to mate with the curvilinear surface of foot plate 12. In the present example, the block 16 has a preferred thickness, at its front 66, of about 1 to 3 inches (about 2.5 to 8 cm), more preferably about 1.3 inches (about 3.4 cm). Its thickness tapers to a minimum of about 0.5 to 1 inch (about 1 to 2.54 cm), more preferably about 0.8 inches (about 2 cm) adjacent arch portion 58. The rear 64 of the block 16 is preferably about 1 to 4 inches (about 2.5 to 10 cm) thick, more preferably about 2.6 inches (about 6.6 cm) thick, which is about twice the thickness of the front portion 66 of the block 16. This gives the ankle block a substantially wedge shape. The greater thickness at the rear of block 16 is provided to impart additional support in the rear portion 64 of the ankle block due to greater compressive forces on the rear of the foot prosthesis caused by off-axis application of force relative to axis 70 during heel strike (see FIG. 5A).

The ankle block 16 may be provided in varying heights or thicknesses, as desired, but is most effective with a thickness of between about 1 and 4 inches (about 2.54 and 10 cm). The front portion and rear surfaces of ankle block 16 are preferably angled according to the angle γ defined by the plane P_3 and the ankle plate 14. In other words, the ankle block has front and rear surfaces which are preferably sloped forward at an angle γ from vertical. The ankle block thus provides a relatively stiff, yet flexible ankle region which can be customized for various wearers. Heavier wearers may require a denser resilient material for the ankle block, while lighter wearers may require a less dense material or less thickness.

As shown in FIGS. 2 and 3, the spring element 18 is positioned in the ankle block such that the center of the spring element 18, at the position of fastener 26, is located approximately above the arch portion 58 of foot plate 12. The two members 22, 24 of the spring element 18 preferably have a constant thickness of about 0.05 to 0.2 inches (about 0.1 to 0.5 cm). The distance between the two members at front end 82, when no load is impressed onto the foot 10, is preferably about 0.5 and 2 inches (about 1 to 5 cm), more preferably about 0.7 inches (about 1.8 cm). At rear end 80, when no load is impressed on the foot 10, the distance between members 22 and 24 is about 1 to 3 inches (about 2.5 to 7.5 cm), more preferably about 1.4 inches (about 3.5 cm). As described in further detail below, when the foot is in a heel-strike position, the rear end 80 of the spring element is compressed. When the foot is in a toe-off position, the forward end 82 of the spring element is compressed.

The lengths, widths and thicknesses of the foot plate 12 ankle plate 14, ankle block 16 and spring element 18 may be customized for the wearer according to his/her foot size as well as the approximate weight group of the wearer. Likewise, the material choice and size for these elements may be varied according to the wearer's foot size and weight.

The cylindrical openings 50, 51 provided in the fore and aft portions of ankle block 16 preferably have a diameter of about 0.1 to 0.4 inches (about 0.25 to 1 cm), and more preferably, about 0.2 inches (about 0.5 cm). While the openings 50 and 51 shown in FIG. 2 have the same diameter, the diameters of the openings may be different to accommodate different sized stiffeners. For instance, the diameter of opening 51 may be made larger than the diameter of opening 50 to correspond with the greater volume of ankle block 16 in rear portion 64.

Performance Characteristics

To more fully explain the improved performance characteristics of the present prosthetic foot 10, FIGS. 5A–5D show "snapshots" of a prosthetic foot in several positions of a walking stride. More particularly, FIG. 5A shows a heel-strike position, FIG. 5B shows a generally flat or mid-stance position, FIG. 5C shows a heel-off position, and FIG. 5D shows a toe-off position. Throughout the various positions shown for a walking stride, the present prosthetic foot 10 provides a smooth and generally life-like response to the wearer. During a walking stride, the ankle block 16 transmits the forces imparted thereon by the foot plate 12 and ankle plate 14, and experiences a gradual rollover, or migration of the compressed region, from rear to front.

With specific reference to FIG. 5A, a first position of a walking stride generally entails a heel strike, wherein the wearer transfers all of his or her weight to the heel of the leading foot. In this case, a rear portion 54 of the foot plate 12 comes in contact with a ground surface 68, albeit through the cosmesis 30. The flexible nature of the foot plate 12 allows it to bend slightly in the rear portion 54, but most of the compressive stresses from the weight of the wearer through the prosthetic foot 10 to the foot plate 12 are absorbed by a rear region 64 of the ankle block 16 with spring element 18. The spring element 18 in the rear portion contracts, such that the distance between members 22 and 24 at rear end 80 decreases. In a front region 66 of the ankle block 16, the spring element 18 may expand slightly such that the distance between members 22 and 24 at front end 82 increases. Front portion 66 of the ankle block 16 experiences a stretching, or tension, due to the attachment along the entire lower edge of the ankle block with the foot plate 12 while rear portion 64 experiences compression. The contraction of the spring element 18 at end 80 and ankle block 16 at end 64 allows the prosthesis 10 to absorb and store energy from the compressive stresses during heel strike. Further, a slight amount of bending may occur in a rear region 68 of the ankle plate 14. The rear stiffener 53 between members 22 and 24 is compressed so as to provide necessary support to the foot prosthesis and to prevent separation of the members 22, 24 from the wedge 28. Front stiffener 52 is slightly stretched substantially vertically due to the tension forces at front portion 66 of ankle block 16.

Next, in FIG. 5B, the wearer reaches a generally flat-footed or mid-stance position, whereby the foot plate 12 contacts the ground 68 along substantially its entire length, again through the cosmesis 30. In this position the weight of the wearer is directed substantially downwardly, so that the compression along the length of the ankle block 16 is only slightly greater in the rear portion 64 than in front portion 66, due to the off-center application of force. In both the fore and rear ends of spring element 18, the members 22 and 24 are compressed towards each other, with the rear end 80 being slightly more compressed from its original position than the forward end 82. Likewise, stiffeners 52 and 53 are compressed due to the downward application of force. Although this view freezes the compressive stress distribution as such, in reality the weight of the wearer is continually shifting from behind the centerline 70 of the attachment member 34 to forward thereof. Thus, as the wearer continues through the stride, the compression of the ankle block 16 and the elements embedded within travels from the rear portion 64 toward the front portion 66. This migration of the compressed region can be termed "rollover."

In a next snapshot of the walking stride, FIG. 5C shows the prosthetic foot 10 in a "heel-off" position. This is the instant when the wearer is pushing off using ball 72 and toe 74 regions of the foot. Thus, a large compressive force is generated in the front region 66 of the ankle block 16, causing the rear region 64 to experience a large amount of separation or tension. Similarly, the spring element 18 at the rear end 80 expands between the two members 22, 24, while it compresses in the front end 82. The front tip 56 of the foot plate 12 may bend substantially to absorb some of the compressive stresses. Likewise, the front tip 60 of the ankle plate 14 may bend somewhat at this point. It is important to note that although the ankle block 16 absorbs a majority of the compression generated by the wearer, the foot plate 12 and ankle plate 14 are designed to work in conjunction with the resilient ankle block and spring element and provide enhanced dynamic performance. Further, the flexing of the foot plate 12 and ankle plate 14 relieves some of the extreme shear stresses applied to the interfaces between the ankle block 16 and plates, thus increasing the life of the bonds formed therebetween. The stiffener 52 located in the front 66 of the ankle block 16 compresses so as to limit compression of front end 82, giving the wearer balance and to prevent separation of the members 22, 24 from the wedge 28. Stiffener 53 extends due to the separation of ankle block 16 in rear portion 64.

In FIG. 5D, a final position of the walking stride is shown, wherein the prosthetic foot 10 remains in contact with the ground 68, but some of the weight of the wearer is being transferred to the opposite foot, which has now moved forward. In this "toe-off" position, there is less bending of the front tip 56 of the foot plate 12 and less compression of the front portion 66 of the ankle block 16 and front end 82 of spring element 18. Likewise, the front tip 60 of the ankle plate 14 may flex a slight amount, depending on the material and thickness utilized. The region of highest compression of the ankle block 16 remains at the farthest forward region 66, but it is reduced from the compression level of the heel-off position of FIG. 5C. Thus, the rear portion 64 of the ankle block 16 experiences a small amount of tension or spreading.

It can now be appreciated that the "feel" of the present prosthetic foot is greatly enhanced by the cooperation between the foot plate, ankle plate, ankle block and spring inserts. As the wearer continues through the walking stride the dynamic response from the prosthetic foot is smooth as the ankle block with spring inserts compresses in different regions. Further, the flexing of the ankle and foot plates assist in smoothly transmitting the various bumps and jars found in uneven walking surfaces.

Alternative Embodiments

It will be appreciated that alternative embodiments of a prosthetic foot having an ankle block with a spring insert are

also encompassed by this invention. One such alternative embodiment is shown in FIG. 6. Reference numerals for FIG. 6 generally correspond to the reference numerals used in FIGS. 1–5D for like elements. Thus, the prosthetic foot 10 shown in FIG. 6 generally comprises a lower foot plate 12 an upper, smaller ankle plate 14, an ankle layer or block 16 made of resilient material, connecting the foot plate 12 to the ankle plate 14, and a spring element 18 embedded within the ankle block. The foot plate 12 has a length and width roughly equal to the approximate length and width of the particular wearer's amputated foot and sized to fit within an outer, flexible cosmesis 30, shown in phantom. As shown in FIG. 6, the ankle plate 14 has a substantially arcuate curvature extending from the integrally formed attachment member 34 to the front of the ankle plate 14.

More particularly, the spring element 18 as illustrated in FIG. 6 is a resilient support member inserted within the resilient ankle block 16. The spring element 18 shown in FIG. 6 is preferably a plate-like member with a curvilinear concave downward shape and a substantially rectangular vertical projection. The spring element 18 is preferably made from a carbon fiber composite material such as described hereinbefore, although other similar materials may be used as well.

The embodiments illustrated and described above are provided merely as examples of certain preferred embodiments of the present invention. Other changes and modifications can be made from the embodiments presented herein by those skilled in the art without departure from the spirit and scope of the invention as defined by a fair reading of the appended claims.

What is claimed is:

1. A prosthetic foot for attaching to a socket or pylon of a lower-limb amputee, comprising:

- a foot plate element having a length approximately equal to the length of a human foot, the foot plate element comprising a resilient material capable of flexing along its length;
- an ankle plate element having a length substantially shorter than the foot plate element;
- an ankle block comprising a relatively soft, compressible material sandwiched between the ankle plate element and the foot plate element, the ankle block providing energy storage and support and connection between the foot plate element and the ankle plate element; and
- a spring element embedded within the ankle block for providing additional energy storage and support, said spring element having a posterior portion configured to compress during heel-strike, and an anterior portion configured to compress during toe-off;
- whereby the foot plate element, the ankle block, and the spring element flex in a cooperative manner to provide substantially smooth and continuous rollover transition from heel-strike to toe-off.

2. The prosthetic foot of claim 1, wherein the foot plate element has a tapered thickness along its length, such that the thickness increases from a heel section to an arch section and decreases from the arch section to a toe section.

3. The prosthetic foot of claim 2, wherein the heel and toe sections are formed substantially concave-up and the arch section is formed substantially concave-down.

4. The prosthetic foot of claim 1, wherein the ankle block has a substantially planar upper surface and a curvilinear lower surface, the upper surface mating with a bottom surface of the ankle plate element, the lower surface mating with a top surface of the foot plate element.

5. The prosthetic foot of claim 1, wherein the ankle plate element, the ankle block and the spring element are centered transversely with respect to and are generally positioned over a back half of the foot plate element.

6. The prosthetic foot of claim 1, wherein the ankle block is made of a foam block having a density between about 150 and 1500 kg/m^3.

7. The prosthetic foot of claim 1, wherein the spring element is formed from a carbon fiber composite material.

8. The prosthetic foot of claim 1, wherein the spring element comprises upper and lower relatively flat members secured at their center by a fastener and separated at their ends.

9. The prosthetic foot of claim 8, wherein the upper member is substantially curvilinear concave upward and the lower member is substantially curvilinear concave downward.

10. The prosthetic foot of claim 1, further comprising at least one opening extending through the ankle block adapted to receive a stiffener for adjusting the spring characteristics of the prosthetic foot.

11. The prosthetic foot of claim 10, wherein a first and second cylindrical opening extend through the ankle block, the first opening being positioned in a fore portion of the block and the second opening being positioned in a rear portion of the block.

12. The prosthetic foot of claim 11, wherein tubular stiffeners are placed in the openings.

13. A prosthetic foot, comprising:

- an upper plate;
- a lower plate;
- a compressible layer formed of a compressible material, said compressible material connected to the upper plate and the lower plate and separating the upper plate from the lower plate; and
- a spring element made of resilient material embedded within the compressible layer and spaced apart from the upper and lower plates, said spring element configured to store and release walking energy during ambulation of said prosthetic foot.

14. The prosthetic foot of claim 13, wherein the lower plate has a length and a width roughly equal to the approximate length and width of an amputated foot.

15. The prosthetic foot of claim 13, wherein the upper plate and the compressible layer have approximately the same cross-sectional size.

16. The prosthetic foot of claim 13, wherein the compressible layer is made of a foam material having a density between about 150 and 1500 kg/m^3.

17. The prosthetic foot of claim 13, wherein the spring element is made of a carbon fiber material.

18. The prosthetic foot of claim 13, wherein the spring element has a substantially double wishbone shape.

19. The prosthetic foot of claim 13, wherein the spring element is a plate-like member with a curvilinear concave downward shape.

20. The prosthetic foot of claim 13, wherein the spring element is a foam material having a density between about 150 and 1500 kg/m^3.

21. The prosthetic foot of claim 13, wherein the spring element is a tubular member inserted into the compressible layer.

22. A prosthetic foot including a resilient ankle block for separably mounting between a foot plate and an ankle plate of a prosthetic foot for providing resilient kinematic support to an amputee relative to a ground surface, the ankle block comprising a block of resilient material and at least one

spring insert embedded within the block of resilient material, said spring insert configured to store and release walking energy during ambulation of said prosthetic foot, said ankle block being substantially the sole means of connection and support between said foot plate and said ankle plate.

23. The prosthetic foot of claim 22, wherein the block of resilient material is an expanded polyurethane having a density between about 150 and 1500 kg/M^3.

24. The prosthetic foot of claim 23, wherein the expanded polyurethane has a density of about 500 kg/m^3.

25. The prosthetic foot of claim 22, wherein a first spring insert comprises upper and lower substantially plate-like members joined at their center and separated at their ends, the upper member being substantially curvilinear concave upward and the lower member being substantially curvilinear concave downward.

26. The prosthetic foot of claim 25, wherein the first spring insert is made of a carbon fiber composite material.

27. The prosthetic foot of claim 25, wherein a second spring insert comprises at least one tubular stiffener.

28. The prosthetic foot of claim 27, wherein a first tubular stiffener is positioned in a fore region of the ankle block between the upper and lower substantially plate-like members, and a second tubular stiffener is positioned in an aft region of the ankle block between the upper and lower substantially plate-like members.

29. The prosthetic foot of claim 28, wherein the first and second tubular stiffeners are made of an expanded polyurethane having a density between about 150 and 1500 kg/m^3.

30. The prosthetic foot of claim 29, wherein the first and second tubular stiffeners are made of an expanded polyurethane having a density of between about 250 and 750 kg/m^3.

31. The prosthetic foot of claim 22, wherein the at least one spring element is a plate-like member having a substantially curvilinear downward shape.

32. A prosthetic foot, comprising:

a support plate made of a resilient material and having a length approximately equal to the length of a human foot;

a layer of compressible material mounted to the support plate; and

a spring element comprising at least one substantially plate-like member embedded within the layer of compressible material, said plate-like member configured to store and release walking energy.

33. The prosthetic foot of claim 32, wherein the layer of compressible material is foam.

34. The prosthetic foot of claim 32, wherein the spring element is made of a carbon fiber material.

35. The prosthetic foot of claim 32, wherein the spring element comprises a pair of substantially plate-like members, the plate-like members being secured at their center and separated at their ends.

36. The prosthetic foot of claim 32, wherein the at least one substantially plate-like member has a curvilinear concave downward shape.

37. A prosthetic foot for attaching to a socket or pylon of a lower-limb amputee, comprising:

a foot plate element having a length approximately equal to the length of a human foot, the foot plate element comprising a resilient material capable of flexing along its length;

an ankle plate element having a length substantially shorter than the foot plate element;

an ankle block comprising a relatively soft, compressible material sandwiched between the ankle plate element and the foot plate element, the ankle block providing energy storage and support and connection between the foot plate element and the ankle plate element; and

a spring element embedded within the ankle block for providing additional energy storage and support, said spring element being formed from a carbon fiber composite material;

whereby the foot plate element, the ankle block, and the spring element flex in a cooperative manner to provide substantially smooth and continuous rollover transition from heel-strike to toe-off.

38. A prosthetic foot for attaching to a socket or pylon of a lower-limb amputee, comprising:

a foot plate element having a length approximately equal to the length of a human foot, the foot plate element comprising a resilient material capable of flexing along its length;

an ankle plate element having a length substantially shorter than the foot plate element;

an ankle block comprising a relatively soft, compressible material sandwiched between the ankle plate element and the foot plate element, the ankle block providing energy storage and support and connection between the foot plate element and the ankle plate element; and

a spring element embedded within the ankle block for providing additional energy storage and support, said spring element comprising upper and lower relatively flat members secured at their center by a fastener and separated at their ends;

whereby the foot plate element, the ankle block, and the spring element flex in a cooperative manner to provide substantially smooth and continuous rollover transition from heel-strike to toe-off.

39. The prosthetic foot of claim 38, wherein the upper member is substantially curvilinear concave upward and the lower member is substantially curvilinear concave downward.

40. A prosthetic foot, comprising:

an upper plate;

a lower plate;

a compressible layer connected to the upper plate and the lower plate and separating the upper plate from the lower plate; and

a spring element made of resilient material embedded within the compressible layer and spaced apart from the upper and lower plates, said spring element being made of a carbon fiber material.

41. A prosthetic foot, comprising:

an upper plate;

a lower plate;

a compressible layer connected to the upper plate and the lower plate and separating the upper plate from the lower plate; and

a spring element made of resilient material embedded within the compressible layer and spaced apart from the upper and lower plates, said spring element having a substantially double wishbone shape.

42. A prosthetic foot, comprising:

an upper plate;

a lower plate;

a compressible layer connected to .he upper plate and the lower plate and separating the upper plate from the lower plate; and

an energy storing spring element made of resilient material embedded within the compressible layer and spaced apart from the upper and lower plates, said spring element comprising a plate-like member with a curvilinear concave downward shape.

43. A prosthetic foot including a resilient ankle block for separably mounting between a foot plate and an ankle plate of a prosthetic foot for providing resilient kinematic support to an amputee relative to a ground surface, the ankle block comprising a block of resilient material and at least one spring insert embedded within the block of resilient material, wherein a first spring insert comprises upper and lower substantially plate-like members joined at their center and separated at their ends, the upper member being substantially curvilinear concave upward and the lower member being substantially curvilinear concave downward.

44. The prosthetic foot of claim 43, wherein the first spring insert is made of a carbon fiber composite material.

45. The prosthetic foot of claim 43, wherein a second spring insert comprises at least one tubular stiffener.

46. The prosthetic foot of claim 45, wherein a first tubular stiffener is positioned in a fore region of the ankle block between the upper and lower substantially plate-like members, and a second tubular stiffener is positioned in an aft region of the ankle block between the upper and lower substantially plate-like members.

47. The prosthetic foot of claim 46, wherein the first and second tubular stiffeners are made of an expanded polyurethane having a density between about 150 and 1500 kg/m^3.

48. The prosthetic foot of claim 47, wherein the first and second tubular stiffeners are made of an expanded polyurethane having a density of between about 250 and 750 kg/m^3.

49. A prosthetic foot including a resilient ankle block for separably mounting between a foot plate and an ankle plate of a prosthetic foot for providing resilient kinematic support to an amputee relative to a ground surface, the ankle block comprising a block of resilient material and at least one energy storing spring insert embedded within the block of resilient material, wherein the at least one spring insert is a plate-like member having a substantially curvilinear downward shape.

50. A prosthetic foot, comprising:

a support plate made of a resilient material and having a length approximately equal to the length of a human foot;

a layer of compressible material mounted to the support plate; and

a spring element comprising at least one substantially plate-like member embedded within the layer of compressible material, said spring element being made of a carbon fiber material.

51. A prosthetic foot, comprising:

a support plate made of a resilient material and having a length approximately equal to the length of a human foot;

a layer of compressible material mounted to the support plate; and

a spring element comprising a pair of substantially plate-like members being secured at their center and separated at their ends, at least one of said plate-like members being embedded within the layer of compressible material.

52. A prosthetic foot, comprising:

a support plate made of a resilient material and having a length approximately equal to the length of a human foot;

a layer of compressible material mounted to the support plate; and

a spring element comprising at least one substantially plate-like member embedded within the layer of compressible material and having a curvilinear concave downward shape.

* * * * *

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United States Patent [19]

C rnelius

[11] **Patent Number:** **5,571,212**

[45] **Date of Patent:** **Nov. 5, 1996**

[54] **PROSTHETIC ANKLE JOINT FOR PIVOTALLY CONNECTING A RESIDUAL LIMB TO A PROSTHETIC FOOT**

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[21] Appl. No.: **371,024**

[22] Filed: **Jan. 10, 1995**

[51] **Int. Cl.**^{6} **A61F 2/60**

[52] **U.S. Cl.** **623/48**; 623/47; 623/49; 623/52

[58] **Field of Search** 623/52, 47, 48, 623/49, 50, 51

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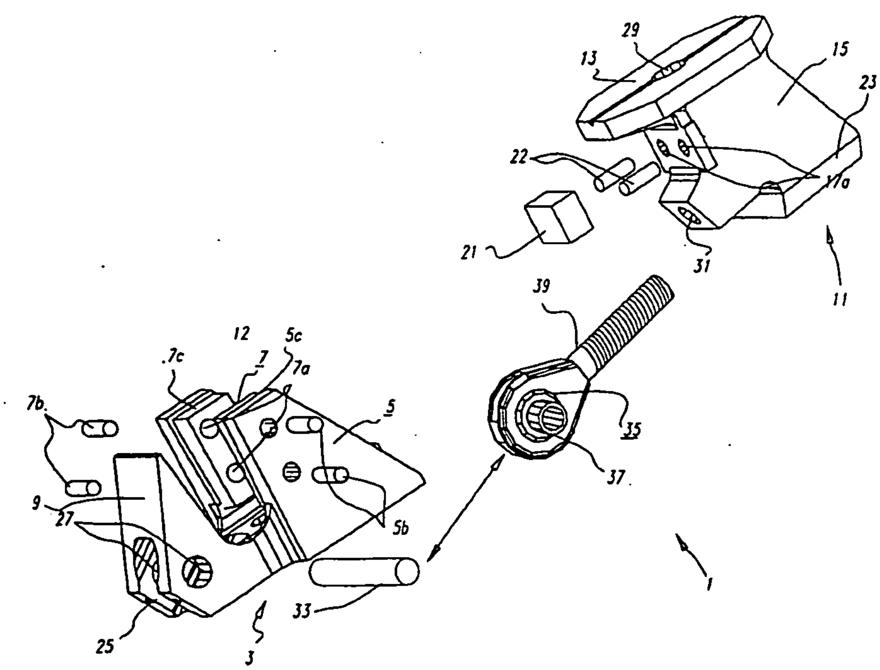
Assistant Examiner—Bruce E. Snow
Attorney, Agent, or Firm—Seed and Berry LLP

[57] **ABSTRACT**

A prosthetic ankle joint includes a first joint structure having a foot attachment plate connecting a pair of spaced apart parallel fins lying in a sagital plane. A second joint structure having a pylon attachment plate is connected to a support block positioned between the fins of the first joint structure. The first and second joint structures are connected to each other by a spherical bearing that allows the joint structures to pivot with respect to each other about three orthogonal axes. The spherical bearing is connected to the first joint structure through an axle that extends through an aperture in the bearing. A rod extending from the bearing is threaded into a bore formed in the support block of the second joint structure. Dorsiflexion and plantar flexion cushions are positioned between the support block and respective surfaces of the first joint structure to resist pivotal dorsiflexal and plantar flexal pivotal movement of the ankle joint. Lateral cushions are positioned on opposite surfaces of the support block between the support block and respective fins to resist coronal and transverse pivotal movements of the ankle joint.

23 Claims, 6 Drawing Sheets



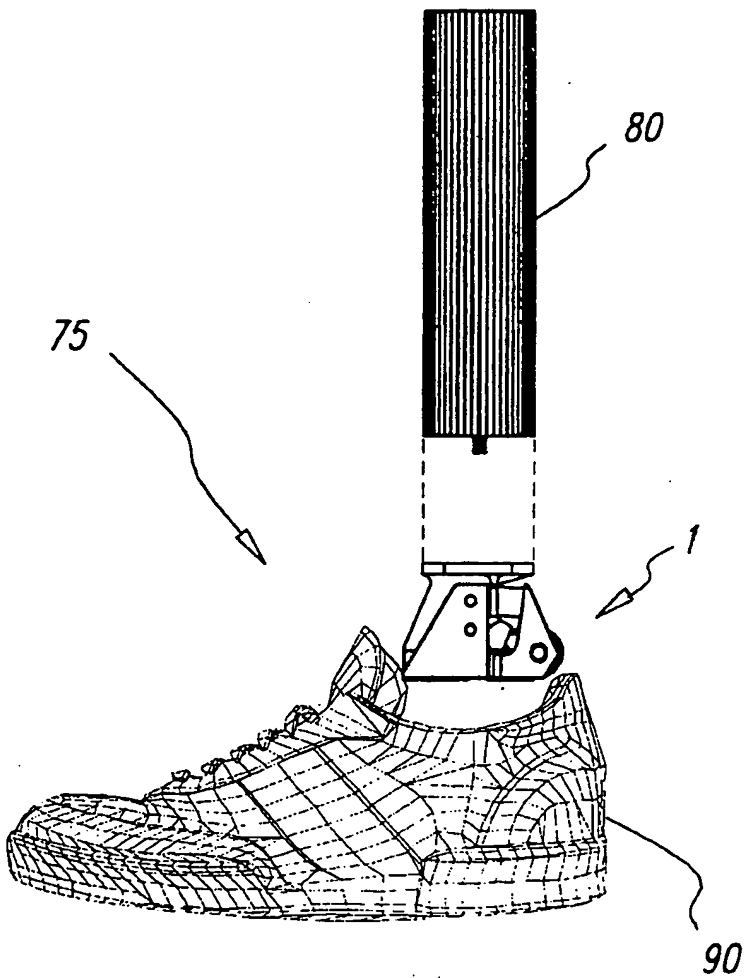


Fig. 1

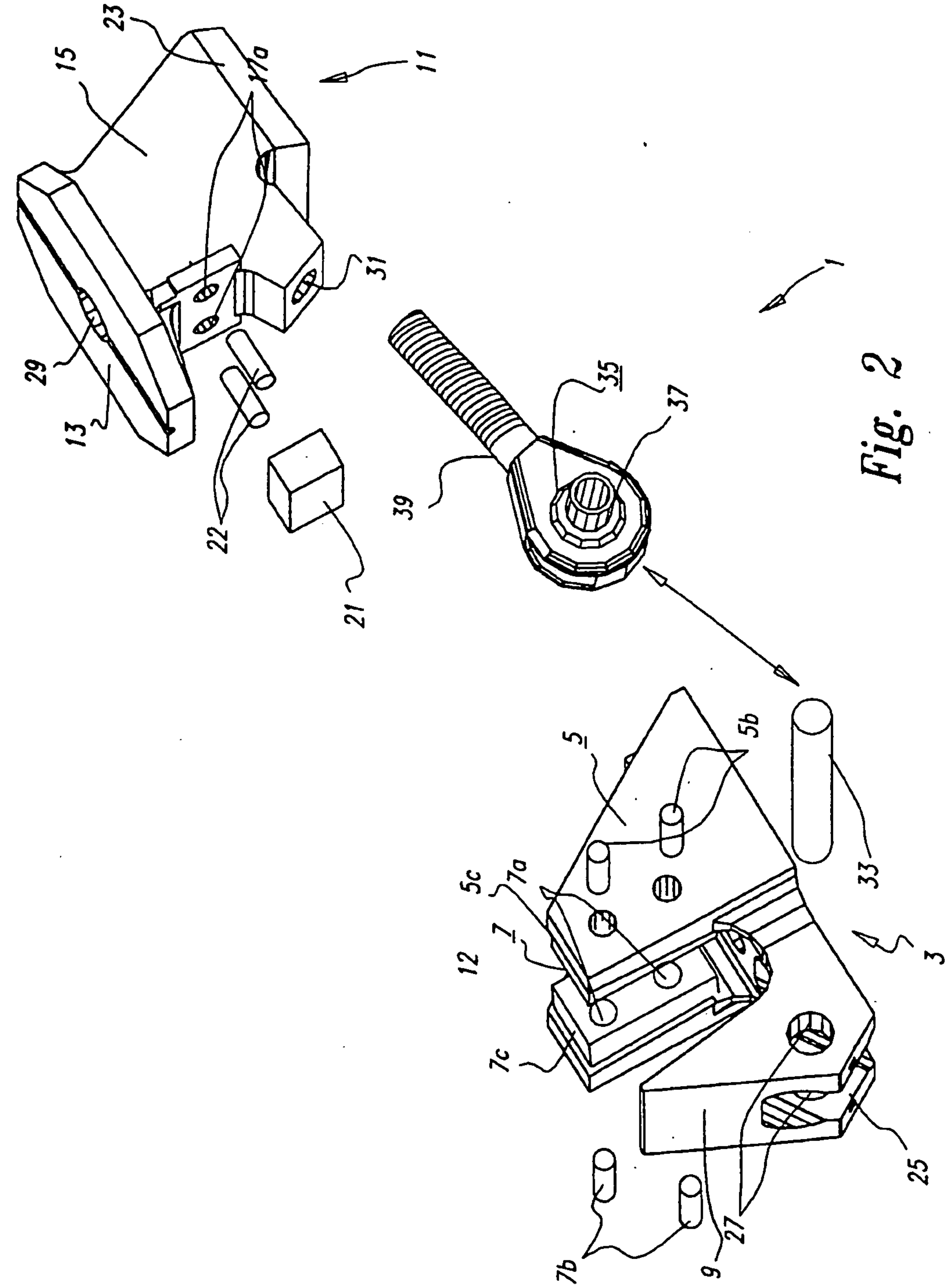


Fig. 2

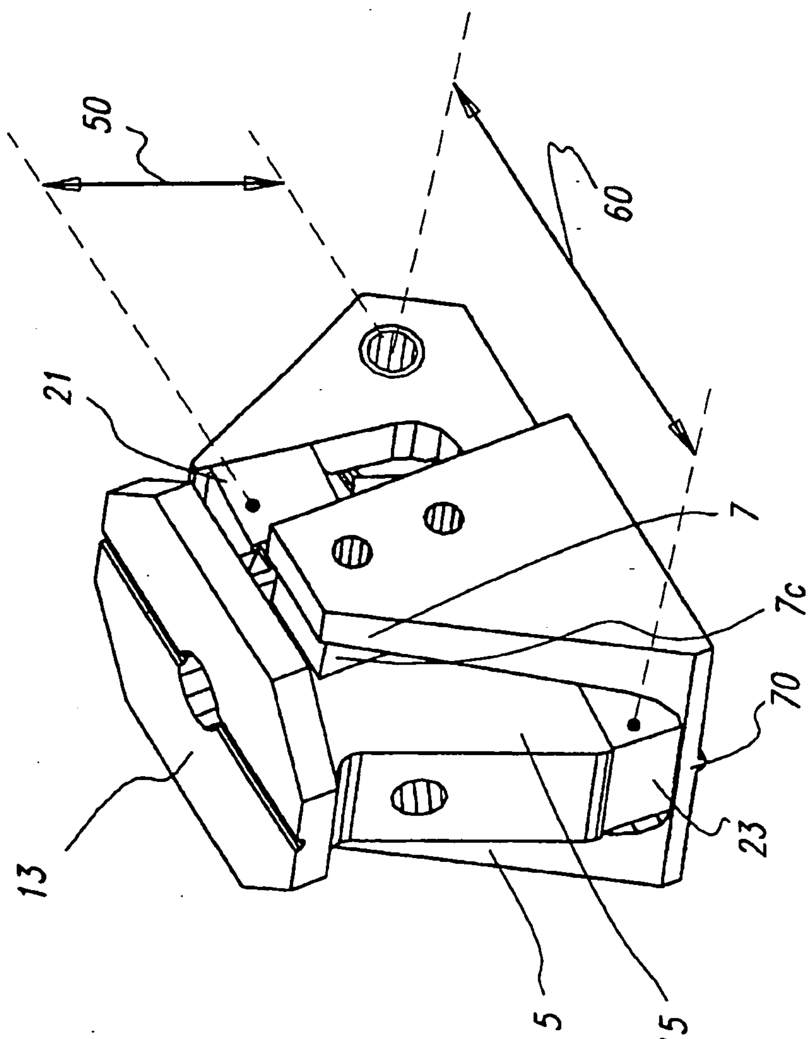


Fig. 3

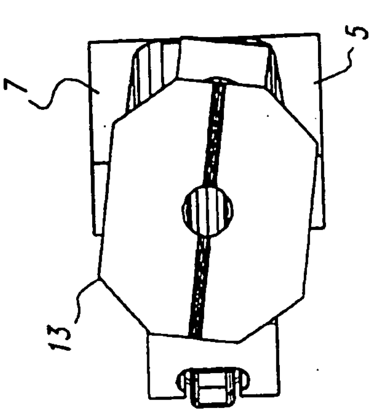


Fig. 4e

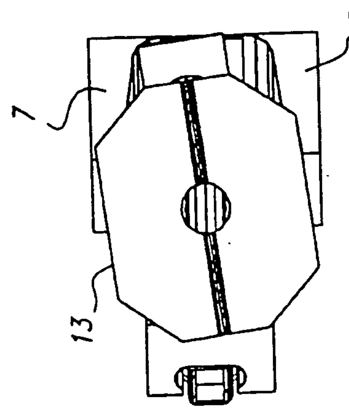


FIG. 4f

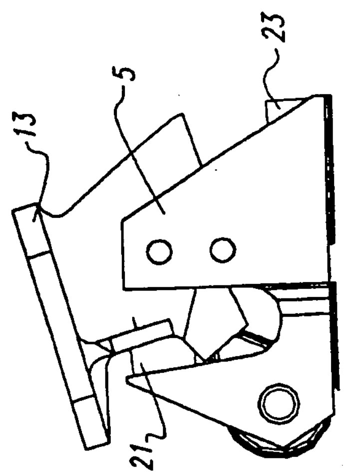


Fig. 4c

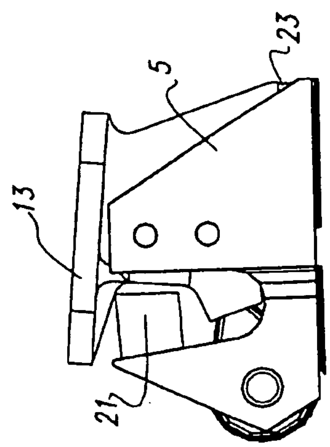


Fig. 4d

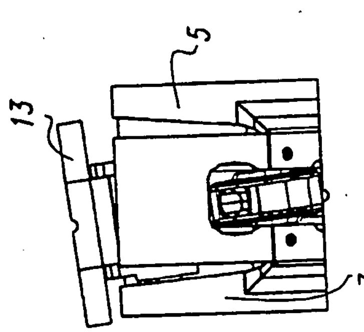


Fig. 4a

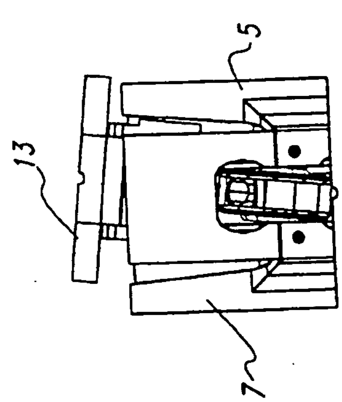


Fig. 4b

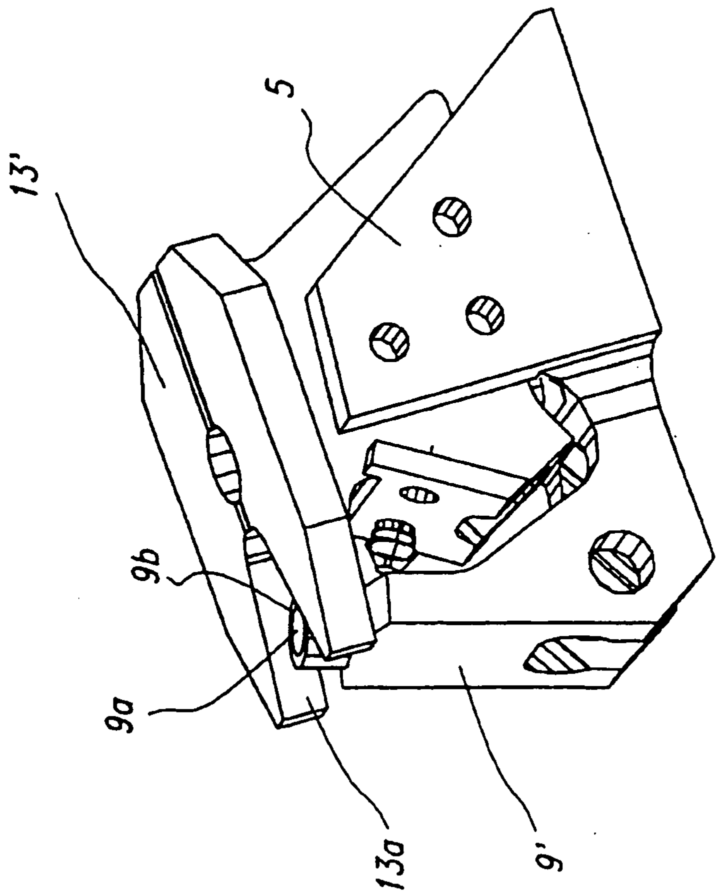


Fig. 5

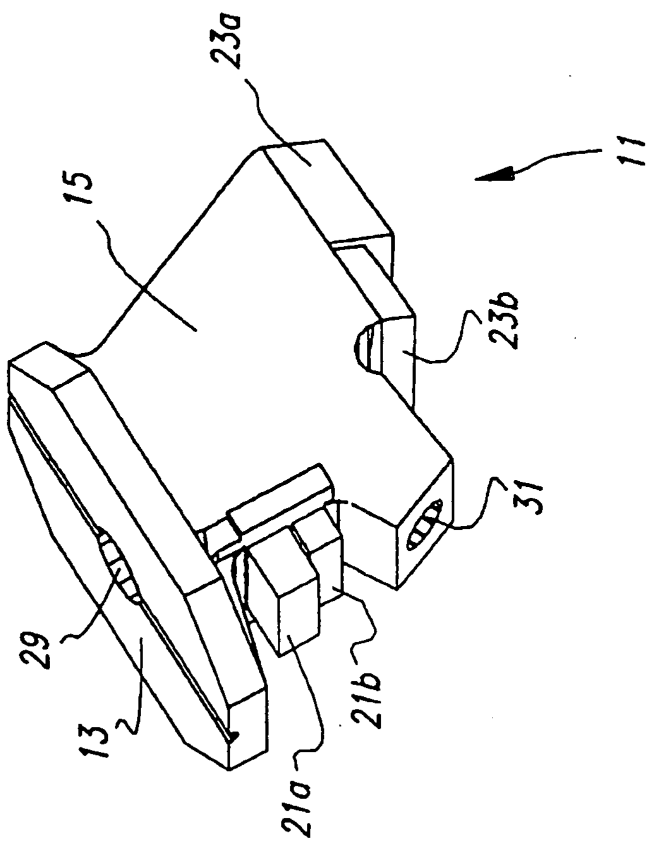


Fig. 6

PROSTHETIC ANKLE JOINT FOR PIVOTALLY CONNECTING A RESIDUAL LIMB TO A PROSTHETIC FOOT

TECHNICAL FIELD

The present invention relates to a prosthetic ankle joint, and more particularly, to a prosthetic ankle joint having flexion characteristics that vary as a function of the flexure position of the ankle joint.

BACKGROUND OF THE INVENTION

Individuals who lose all or part of a leg have a residual limb to which a prosthetic foot is often attached through an elongated pylon. The attachment between the lower end of the pylon and the prosthetic foot approximates an ankle joint. However, in the past, pylons have been rigidly attached to prosthetic feet, thus creating a rigid ankle joint. Rigid ankle joints have typically relied on a cushion in the heel of the prosthetic foot to allow relative axial motion between the residual limb and the ground. However, this approach has proven to be inadequate because it makes the individual walk awkwardly, and prone to stumble when standing on an incline.

The basic problem with a rigid ankle joint is that it does not mimic a real ankle. As a result, prosthetic designers have developed pivotal ankle joints. Such ankle joints typically provide some motion in three orthogonal planes, namely the sagital, coronal, and transverse planes. A transverse plane is orthogonal to the longitudinal axis of the residual limb, and movement in the transverse plane is known as transverse adduction or abduction of the foot, or transverse rotation. A sagital plane is a vertical front-to-back plane, and movement in the sagital plane is known as either dorsiflexion in which the toe pivots upwardly or plantar flexion in which the toe pivots downwardly. The coronal plane is a vertical plane orthogonal to the transverse, and rotation in the coronal plane is coronal rotation, i.e., inversion or eversion of the foot.

Some of these pivotal ankles allow for these motions by attaching the residual limb to the prosthetic foot with a resilient material. The resilient material allows the residual limb to move relative to the prosthetic foot in any direction. One problem with such ankles is that they do not allow the resistance of the ankle to dorsiflexion and plantar flexion to be independently adjusted. It is known that it is desirable for the ankle to have greater resistance to dorsiflexion than to plantar flexion so the individual using it will have a natural walking gait. Thus, these ankles are inadequate because they make the individual walk awkwardly.

Some other pivotal ankles do allow independent adjustment of the resistance to plantar flexion and dorsiflexion. An example of such an ankle is U.S. Pat. No. 4,645,508, to Shorter et al. This ankle has a residual limb mounted vertically on a ball and socket joint having an outer sleeve which skirts the front and both sides of the shank of the ball. A ring of resilient material surrounds the shank of the ball and is fitted underneath the sleeve. During dorsiflexion the sleeve restricts expansion of the resilient material as it is compressed by the socket, thus providing resistance to dorsiflexion. During plantar flexion the resilient material is free to expand while it is compressed by the socket, thus providing less resistance to plantar flexion. One problem with this ankle is that because it uses the same ring for dorsiflexion and plantar flexion, it can only provide gross adjustments in resistance. For the individual to have a natural walking gait, fine adjustments are necessary.

Other pivotal ankles can provide finer adjustments by using different resilient materials for dorsiflexion and plantar flexion. An example of such an ankle is U.S. Pat. No. 3,851,337, to Prahl. The ankle disclosed in the Prahl patent has a shaft extending along the longitudinal axis of a residual limb which terminates in an eye socket. The eye socket is pressed onto a spherical bearing which is fitted on an axle mounted in a prosthetic foot. A second spherical bearing is fitted about the shaft of the residual limb, and a second eye socket is pressed onto the second bearing and is connected to a shaft extending toward the toe of the prosthetic foot. The shaft fits through a third spherical bearing and extends into a cylinder. Inside the cylinder both dorsiflexion and plantar flexion are independently resisted by separate cushions of resilient material. By adjusting the resilience of these two cushions, resistance to plantar flexion and dorsiflexion can be independently controlled. However, this ankle requires a complex linkage of sockets and bearings in order to do this while keeping the residual limb mounted vertically over the joint.

Therefore, there is a need in the art for a prosthetic ankle joint of simple construction which provides greater resistance to dorsiflexion than to plantar flexion.

One object of this invention is to allow an individual who has a residual limb to have a stable and natural walking gait.

Another object is to provide a prosthetic ankle joint which, like a natural ankle, allows dorsiflexion, plantar flexion, coronal rotation, and transverse rotation.

A further object is to provide a prosthetic ankle joint of simple construction.

Still another object is to provide a prosthetic ankle joint which is reliable.

A still further object is to provide a prosthetic ankle joint with greater resistance to dorsiflexion than to plantar flexion.

Additional objects, advantages and novel features of the invention will be set forth in part in the description which follows, and in part will become apparent to those skilled in the art upon examination of the following, or may be learned by practice of the invention. The objects and advantages of the invention may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

SUMMARY OF THE INVENTION

The inventive prosthetic ankle joint includes first and second joint structures connected to each other by a spherical bearing. The joint structures include respective attachment members that allow the joint structures to be secured between a pylon and a prosthetic foot. The first joint structure preferably includes first and second spaced apart fins each of which substantially lie in a sagital plane. A lateral restraining member attached to the second joint structure has a lateral restraining member positioned between the first and second fins. The spherical bearing pivotally interconnects the joint structures so that they pivot with respect to each about three orthogonal axes. A dorsiflexion cushion is positioned between the first and second joint structures at a location causing the dorsiflexion cushion to be compressed during dorsiflexal pivotal movement of the ankle joint. Similarly, a plantar flexion cushion is positioned between the first and second joint structures at a location causing the plantar flexion cushion to be compressed during

plantar flexal pivotal movement of the ankle joint. A stop cushion may also be positioned between the first and second joint structures at a location causing the stop cushion to be compressed during one of either dorsiflexal pivotal movement or plantar flexal pivotal movement of the ankle joint and acting in parallel with the primary cushion. The stop cushion is thinner and made of a stiffer material than the primary cushion. As a result, the torsional spring constant of the prosthetic ankle is greater as the stop cushion is compressed. A lateral cushion is positioned between the lateral restraining member and each of the first and second fins so that the lateral cushions are compressed during coronalflexal and transversflexal pivotal movement of the ankle joint in opposite directions. The pivot point of the spherical bearing is preferably offset from the location where the user's weight is applied to the ankle joint so that the user is supported by both a cushion and the spherical bearing. As a result, the cushion not only provides resistance to dorsiflexion or plantar flexion, but it also cushions the downward force exerted on the ankle by the weight of the user. One of the joint structures may also include a plate lying in a transverse plane having a v-shaped notch extending inwardly from a transverse rear edge of the plate. A restraining member projecting into the notch from the other joint structure causes the restraining member to move into a narrower portion of the notch during plantar flexal movement to progressively stabilize the ankle joint in the coronal plane as the ankle joint pivots in plantar flexion. The dorsiflexion cushion is preferably spaced from the pivot axis of the bearing by a distance that is different than the spacing between the plantar flexion cushion and the bearing. As a result, the torsional spring constant of the prosthetic ankle in dorsiflexion may be different from the torsional spring constant of the prosthetic ankle in plantar flexion using the stone material for the dorsiflexion and plantar flexion cushions.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features of the present invention will become better understood with regard to the following description, appended claims, and accompanying drawings where:

FIG. 1 is a side elevational view of a walking system using the inventive prosthetic ankle joint.

FIG. 2 is an exploded isometric view of a preferred embodiment of the inventive prosthetic ankle joint.

FIG. 3 is an isometric view of the prosthetic ankle joint of FIG. 1 shown in assembled configuration.

FIGS. 4(*a*) and (*b*) are rear elevational views of the prosthetic ankle joint of FIG. 1 showing how the ankle joint accommodates coronal rotation.

FIGS. 4(*c*) and (*d*) are side elevational views of the prosthetic ankle joint of FIG. 1 showing plantar flexion and dorsiflexion.

FIGS. 4(*c*) and (*f*) are top plan views of the prosthetic ankle joint of FIG. 1 showing how the ankle joint accommodates transverse rotation.

FIG. 5 is an isometric view of another embodiment of the inventive prosthetic ankle joint having coronal rotation limits that vary as a function of plantar flexion and dorsiflexion position.

FIG. 6 is an isometric view of still another embodiment of the inventive prosthetic ankle joint having stop cushions of less thickness and greater material stiffness than the primary cushion.

DETAILED DESCRIPTION OF THE INVENTION

A prosthetic ankle joint **1** is shown in use in FIG. **1** attached to the lower end of a prosthetic pylon **80** and attached to prosthetic foot **90**. The prosthetic ankle joint is used by individuals who have lost all or part of a leg to connect a residual limb to a prosthetic foot. The prosthetic ankle joint **1** is intended to mimic as much as possible the motion of a natural ankle by giving an individual who has a residual limb a steady and natural gait. This is because it allows the natural motions of dorsiflexion, plantar flexion, coronal rotation, and transverse rotation. The prosthetic ankle joint is also reliable and relatively inexpensive due to its relatively simple construction. Further, the prosthetic ankle joint provides resistance to plantar flexion and dorsiflexion that is independently adjustable. Finally, the prosthetic ankle joint provides resistance to coronal rotation that is independently adjustable.

The preceding advantages are provided using the inventive ankle joint **1**, one embodiment of which is illustrated in FIG. **2**. The prosthetic ankle joint **1** includes a foot attachment structure **3** having a pair of restraining fins **5**, **7** and a support block **9**. Respective cushions **5***c*, **7***c* are mounted on the inner faces of the restraining fins **5**, **7** by respective pins **5***b*, **7***b* for reasons that are explained in greater detail below.

The prosthetic ankle joint **1** also includes a pylon attachment structure **11** having a pylon attachment plate **13** mounted on a base **15**. A pair of cushions **21**, **23** are secured to the base **15** to control the flexion characteristics of the ankle joint, as explained in greater detail below. The cushions **21**, **23** are secured to the base **15** by respective pairs of pins of which the pins **22** for the cushion **21** are shown in FIG. **2**. The pins **22** fit into respective bores **17** formed in base **15**.

The pylon attachment structure **11** is mounted in the foot attachment structure **3** between the restraining fins by a spherical bearing **35**. A threaded stud **39** projects from the bearing **35** and is threaded in a threaded bore **31** formed in the base **15** of the pylon attachment structure **11**. A cylindrical bore **37** formed in the bearing **35** slidably receives a pin **33** that is fixedly inserted through a pair of bores **27** formed in the support block **9** of the foot attachment structure **3**. The slidable mounting of the bearing **35** on the pin **33**, coupled with the characteristic movement of the spherical bearing **35**, allows the pylon attachment structure **11** to rotate about 3 axes while it is maintained in position between the retaining fins **5**, **7**.

The ankle joint **1** is shown in its assembled condition in FIG. **3**. The cushion **5***c* is interposed between the restraining fin **5** and the base **15**, while the other cushion **7***c* is interposed between the restraining fin **7** and the base **15**. The cushions **5***c*, **7***c* thus resiliently limit the relative coronal rotation movement between the foot attachment structure **3** and the pylon attachment structure **11** in the coronal plane, as shown in FIGS. **4***a* and **4***b*. The cushions **5***c*, **7***c* also resiliently limit the relative transverse rotation movement between the foot attachment structure **3** and the pylon attachment structure **11** in the transverse plane as shown in FIGS. **4***e* and **4***f*. The cushion **21** is interposed between the base **15** and the support block **9**. The cushion **21** thus resiliently limits the relative plantar flexion movement between the foot attachment structure **3** and the pylon attachment structure **11** in the sagital plane as shown in FIG. **4***c*. The cushion **23** is interposed between the base **15** and a foot attachment plate **70** (FIG. **3**). The cushion **23** thus resiliently limits the relative dorsiflexion movement

between the attachment structure 3 and the pylon attactment structure 11 in the sagital plane as shown in FIG. 4d. Also, since the pivot axis of the spherical bearing 35 is offset to the rear of where the weight of the user is applied to the pylon attachment plate 13, the weight of the user is supported by both the dorsiflexion cushion 23 and the spherical bearing 35. As a result, the dorsiflexion cushion 23 cushions the downward force exerted by the user during walking in addition to providing resistance to dorsiflexal movement.

As can be seen in FIG. 3, the plantar flexion cushion 21 is a first distance 50 from a longitudinal axis of joint 19. Dorsiflexion cushion 23 is a second distance 60 from the longitudinal axis of joint 19, which is greater than first distance 50. The torque resistance of the dorsiflexion cushion 23 during dorsiflexion is equal to the product of the force exerted by compression of the dorsiflexion cushion 23 and the movement arm 60. Similarly, the torque resistance of the plantar flexion cushion 21 is equal to the product of the force exerted by compression of the plantar flexion cushion 21 and the movement arm 50. Assuming that the spring constants of the cushions 21, 23 are the same, the resistances to dorsiflexion and plantar flexion can be different from each other by simply making the movement arms 50, 60 different from each other.

The angular spring constant K; i.e., the ratio of torque T to angular movement θ can also be calculated. The torque T is given by the formula:

$$T=Fr \tag{1}$$

where F is the force exerted by the compression of the cushion 21, 23 and r is the movement arm 50, 60, respectively. The force F exerted by the compression of the cushions 21, 23 is given by the formula:

$$F=-Kx \tag{2}$$

where K is the spring constant of the cushions and x is the compression distance of the cushions 21, 23. Substituting the force F from equation (2) into equation (1) yields:

$$T=-Kxr \tag{3}$$

For small angular movements θ, the angle θ is equal to sin θ. Using this approximation, the cushion compression distance x can be related to the angular movement θ by the formula:

$$x=r\theta \tag{4}$$

Substituting the cushion compression distance x from formula (4) into formula (3) yields:

$$T=-Kr\theta r=-Kr^2\theta \tag{5}$$

As mentioned above, the angular spring constant K' is equal to the ratio of Torque to angular movement, i.e.:

$$K'=-T/\theta \tag{6}$$

Dividing torque T by angular movement θ in formula (5) yields:

$$T/\theta=-Kr^2 \tag{7}$$

By setting the ratio of T/θ in formula (6) to the ratio of T/θ in formula (7) yields:

$$K'=Kr^2 \tag{8}$$

It is thus seen that the angular spring constant K' is equal to the product of the spring constant K for the cushions 21, 23 and the square of the movement arm 50, 60, respectively.

Thus, the torque resistance of dorsiflexion cushion 23 during dorsiflexion, and of plantar flexion cushion 21 during plantar flexion, will increase as a function of the square of the distance from either cushion to the longitudinal axis of the pin 33. In one version of this embodiment, second distance 60 is greater than first distance 50, thus making resistance during dorsiflexion greater than resistance during plantar flexion. It will be understood, however, that the relative torque resistances during plantar flexion and dorsiflexion can also be varied by using cushions 21, 23 having either different spring constants, different surface areas, different thicknesses, or all three.

In another embodiment of the invention illustrated in FIG. 5, the pylon attachment plate 13' has a coronal stabilization notch 13*a* formed thereon which progressively narrows as it extends into pylon attachment plate 13. In addition, the support block 9' has a coronal stabilization boss 9*a* projecting from the support block 9 into the coronal stabilization notch 13*a*. The coronal stabilization boss 9*a* is surrounded by a bearing 9*b*.

The coronal stabilization bearing 9*b* acts in conjunction with the coronal stabilization notch 13*a* during plantar flexion. As the coronal stabilization boss 9*a* moves progressively into the notch 13*a*, coronalflexion is progressively limited. At full plantar flexion, coronal flexion is substantially restricted to stabilize the walking gait of the individual using the prosthetic ankle joint.

In still another embodiment of the invention illustrated in FIG. 6, two pairs of cushions 21*a*, 21*b*, and 23*a*, 23*b* are secured to the base 15 to control the flexion characteristics of the ankle joint. These cushions perform the same functions as cushions 21 and 23 discussed above. In addition, the cushion 21*b* is thinner and has a greater spring constant than the cushion 21*a*. Similarly, the cushion 23*b* is thinner and has a greater spring constant than the cushion 23*a*. As a result, the force exerted by the compression of cushions 21*a*, 21*b* and 23*a*, 23*b* during dorsiflexion and plantar flexion increases when cushions 21*b*, 23*b* begin to compress. This prevents degradation of cushions 21*a*, 23*a* from over-compression. For example, if the prosthetic ankle joint is in a state of dorsiflexion where the cushion 23*a* is compressed but the cushion 23*b* is not, then the force F exerted by the compression of the cushion 23*a* is given by the formula:

$$F=-K_{23a}x_{23a} \tag{9}$$

where K_{23a} is the spring constant of the cushion 23*a* and x_{23a} is the compression distance of the cushion 23*a*. If the cushion 23*b* is then also compressed, the force F is given by the formula:

$$F=-K_{23a}x_{23a}+-K_{23b}x_{23b} \tag{10}$$

where K_{23b} is the spring constant of the cushion 23*b* and x_{23b} is the compression distance of the cushion 23*b*. Thus, the force F increases as the cushion 23*b* begins to compress, preventing over-compression of the cushion 23*a*.

The spring constants of cushions 21*b*, 23*b* can be made greater than the spring constants of cushions 21*a*, 23*a* by selecting a different material for the cushions with a different modulus of elasticity, by changing the surface area of the cushions, or by changing the thickness of the cushions. This is because the spring constant of the cushion 23*b*, for example, is given by the formula:

$$K_{23b} = \frac{EA}{l} \quad (11)$$

where E is the modulus of elasticity, A is the surface area, and l is the thickness of the cushion **23b**. Thus, for the cushion **23b** to have a greater spring constant than the cushion **23a**, the modulus of elasticity E or the surface area A of the cushion **23b** can be increased, or the thickness the cushion **23b** can be decreased.

As discussed above, the thickness l of cushions **21b**, **23b** is less than the thickness l of cushions **21a**, **23a**. Preferably, the modulus of elasticity E is also selected to be greater for cushions **21b**, **23b** than for cushions **21a**, **23a**. As a result, the spring constants of cushions **21b**, **23b** are greater than the spring constants for cushions **21a**, **23a**, allowing cushions **21a**, **23a** to deform more than cushions **21b**, **23b**. This has the dual benefits of providing cushions **21a**, **23a** which can deform to accommodate the majority of plantar flexural and dorsiflexural motion, respectively, while also providing cushions **21b**, **23b** which carry the majority of the force and keep cushions **21a**, **23a** from over-compression and resulting degradation. This, in turn, makes the prosthetic ankle joint more reliable.

The ankle **1** can be fabricated from any suitable material, such as aluminum, except that the pins **7b**, **5b**, **22**, and **15b** are preferably made of DELRIN™ (ACETAL). The cushions **5c**, **7c**, cushions **21**, **21a**, **21b**, and cushions **23**, **23a**, **23b** can be made of any resilient material.

Although the present invention has been described in detail, with reference to certain preferred versions, other versions are possible. For example, although the restraining fins **5**, **7** are shown as being a part of the foot attachment structure **3**, they could instead be a part of the pylon attachment structure **11**. In this case, the restraining fins **5**, **7** would project downwardly from the foot attachment plate **70** which would now be attached to the pylon, and the pylon attachment plate **13** would be attached to the foot. Therefore, the spirit and scope of the appended claims should not be limited to the description of the preferred versions contained herein.

I claim:

1. A prosthetic ankle joint, comprising:

a first joint structure having a first attachment member attachable to one of either a pylon or a prosthetic foot to receive a force therefrom acting at a first location on the first attachment member, the first joint structure having first and second spaced apart fins each of which substantially lie in a sagital plane;

a second joint structure having a second attachment member attachable to the other of either a pylon or a prosthetic foot to receive a force therefrom acting at a second location on the second attachment member, the second joint structure having a lateral restraining member positioned between the first and second fins;

a spherical bearing interconnecting the first joint structure and the second joint structure so that the first and second joint structures pivot with respect to each other in dorsiflexion, plantar flexion, coronal rotation, and transverse rotation; the pivot point of the spherical bearing being offset from the first and second locations in a direction lying in transverse and sagital planes so that a compressive :force applied between the first and second locations imparts a dorsiflexal or plantar flexal torque about the pivot axis;

a dorsiflexion cushion positioned between the first and second joint structures at a location causing the dorsiflexion cushion to be compressed during dorsiflexal pivotal movement of the ankle joint;

a plantar flexion cushion positioned between the first and second joint structures at a location causing the plantar flexion cushion to be compressed during plantar flexal pivotal movement of the ankle joint; and

a lateral cushion positioned between the lateral restraining member and each of the first and second fins so that the lateral cushions are compressed during coronal rotation and transverse rotation pivotal movement of the ankle joint in opposite directions.

2. The prosthetic ankle joint of claim 1 wherein the spherical bearing is connected to the lateral restraining member between the fins of the first joint structure, and wherein the dorsiflexion, plantar flexion, and lateral cushions are positioned adjacent respective surfaces of the lateral restraining member whereby the lateral restraining member serves the functions of both connecting the second joint structure to the spherical bearing and restraining dorsiflexal, plantar flexal, coronal rotational, and transverse rotational pivotal movement of the second joint structure relative to the first joint structure.

3. The prosthetic ankle joint of claim 2 wherein the second attachment member comprises an attachment flange mounted on the lateral restraining member for attaching the second joint structure to a prosthetic pylon.

4. The prosthetic ankle joint of claim 1 wherein the first attachment member comprises a prosthetic foot attachment plate for attaching the first joint structure to a prosthetic foot, and wherein the second attachment member comprises a prosthetic pylon attachment plate for attaching the second joint structure to a prosthetic pylon.

5. The prosthetic ankle joint of claim 1 wherein one of the joint structures includes a plate lying in a transverse plane, the plate having a v-shaped notch extending inwardly from a transverse edge of the plate, and wherein the other of the joint structures includes a restraining member projecting into the notch so that plantar flexal pivotal movement causes the restraining member to move into a narrower portion of the notch whereby the ankle joint is progressively stabilized in the coronal plane as the ankle joint progressively pivots in the plantar flexal direction.

6. The prosthetic ankle joint of claim 1 wherein the spherical bearing includes a spherical bearing member having an aperture extending therethrough and a rod projecting from the spherical bearing member generally perpendicular to the axis of the aperture, wherein the spherical bearing is attached to the first joint structure by an axle attached to the first joint structure and extending through the aperture of the spherical bearing, and wherein the rod of the spherical bearing is attached to the second joint structure.

7. A prosthetic ankle joint, comprising:

a first joint structure attachable to one of either a pylon or a prosthetic foot;

a second joint structure attachable to the other of either a pylon or a prosthetic foot;

a bearing pivotally interconnecting the first joint structure and the second joint structure so that the first and second joint structures can pivot about a pivot axis in dorsiflexion and plantar flexion;

a dorsiflexion cushion positioned between the first and second joint structures at a first location causing the dorsiflexion cushion to be compressed during dorsiflexal pivotal movement of the ankle joint, the first location being spaced from the pivot axis by a first distance; and

a plantar flexion cushion positioned between the first and second joint structures at a second location causing the

plantar flexion cushion to be compressed during plantar flexal pivotal movement of the ankle joint, the second location being spaced from the pivot axis by a second distance that is different from the first distance so that the torsional spring constant of the prosthetic ankle in dorsiflexion may be different from the torsional spring constant of the prosthetic ankle in plantar flexion using the same material for the dorsiflexion and plantar flexion cushions, the first and second locations both being offset in either a forward or a rearward direction past the pivot point of the bearing so that a compressive force applied between the first and second locations imparts a dorsiflexal torque about the pivot axis whereby the dorsiflexion cushion is compressed by both dorsiflexal pivotal movement between the first and second joint structures and by linear movement between the first and second joint structures toward each other.

8. The prosthetic ankle joint of claim 7 wherein the bearing is a spherical bearing allowing coronal rotational and transverse rotational pivotal movement of the ankle joint as well as dorsiflexal and plantar flexal pivotal movement of the ankle joint.

9. The prosthetic ankle joint of claim 7 wherein the first joint structure includes a prosthetic foot attachment plate for attaching the first joint structure to a prosthetic foot, and wherein the second joint structure includes a prosthetic pylon attachment plate for attaching the second joint structure to a prosthetic pylon.

10. The prosthetic ankle joint of claim 7 wherein one of the joint structures includes a plate lying in a transverse plane, the plate having a v-shaped notch extending inwardly from a transverse edge of the plate, and wherein the other of the joint structures includes a restraining member projecting into the notch so that plantar flexal pivotal movement causes the restraining member to move into a narrower portion of the notch whereby the ankle joint is progressively stabilized in the coronal plane as the ankle joint progressively pivots in the plantar flexal direction.

11. A prosthetic ankle joint comprising:

a first joint structure attachable to one of either a pylon or a prosthetic foot;

a second joint structure attachable to the other of either a pylon or a prosthetic foot, one of the joint structures including a plate lying in a transverse plane, the plate having a v-shaped notch extending inwardly from a transverse edge of the plate, and wherein the other of the joint structures includes a restraining member projecting into the notch so that plantar flexal pivotal movement causes the restraining member to move into a narrower portion of the notch whereby the ankle joint is progressively stabilized in the coronal plane as the ankle joint progressively pivots in the plantar flexal direction;

a bearing pivotally interconnecting the first joint structure and the second joint structure so that the first and second joint structures can pivot about a pivot axis in dorsiflexion and plantar flexion;

a dorsiflexion cushion positioned between the first and second joint structures at a first location causing the dorsiflexion cushion to be compressed during dorsiflexal pivotal movement of the ankle joint, the dorsiflexion cushion having a dorsiflexion cushion thickness in the direction it is compressed;

a plantar flexion cushion positioned between the first and second joint structures at a second location causing the plantar flexion cushion to be compressed during plantar flexal pivotal movement of the ankle joint, the plantar flexion cushion having a plantar flexion cushion thickness in the direction it is compressed; and

a stop cushion positioned between the first and second joint structures at a location causing the stop cushion to be compressed during one of either dorsiflexal pivotal movement or plantar flexal pivotal movement and having a stop cushion thickness in the direction the stop cushion is compressed which is less than one of either the dorsiflexion cushion thickness or the plantar flexion cushion thickness, respectively, so that the torsional spring constant of the prosthetic ankle in one of either dorsiflexion or plantar flexion, respectively, is greater when the stop cushion is compressed than when the stop cushion is not compressed.

12. A prosthetic walking system, comprising:

a prosthetic pylon;

a prosthetic foot;

a prosthetic ankle joint connecting the prosthetic pylon to the prosthetic foot, the ankle joint, comprising:

a first joint structure having a first attachment member attachable to one of either the prosthetic pylon or the prosthetic foot to receive a force therefrom acting at a first location on the first attachment member, the first joint structure having first and second spaced apart fins each of which substantially lie in a sagital plane;

a second joint structure having a second attachment member attachable to the other of either the prosthetic pylon or the prosthetic foot to receive a force therefrom acting at a second location on the second attachment member, the second joint structure having a lateral restraining member positioned between the first and second fins;

a spherical bearing interconnecting the first joint structure and the second joint structure so that the first and second joint structures pivot with respect to each other in dorsiflexion, plantar flexion, coronal rotation, and transverse rotation; the pivot point of the spherical bearing being offset in a rearward direction so that a compressive force applied between the first and second locations imparts a dorsiflexal torque about the pivot axis;

a dorsiflexion cushion positioned between the first and second joint structures at a location causing the dorsiflexion cushion to be compressed during dorsiflexal pivotal movement of the ankle joint;

a plantar flexion cushion positioned between the first and second joint structures at a location causing the plantar flexion cushion to be compressed during plantar flexal pivotal movement of the ankle joint; and

a lateral cushion positioned between the lateral restraining member and each of the first and second fins so that the lateral cushions are compressed during coronal rotational and transverse rotational pivotal movement of the ankle joint in opposite directions.

13. The prosthetic walking system of claim 12 wherein the spherical bearing is connected to the lateral restraining member between the fins of the first joint structure, and wherein the dorsiflexion, plantar flexion, and lateral cushions are positioned adjacent respective surfaces of the lateral restraining member whereby the lateral restraining member serves the functions of both connecting the second joint structure to the spherical bearing and restraining dorsiflexal, plantar flexal, coronal rotational, and transverse rotational

pivotal movement of the second joint structure relative to the first joint structure.

14. The prosthetic walking system of claim 13 wherein the second attachment member comprises an attachment flange mounted on the lateral restraining member for attaching the second joint structure to the prosthetic pylon.

15. The prosthetic walking system of claim 12 wherein the first attachment member comprises a prosthetic foot attachment plate for attaching the first joint structure to the prosthetic foot, and wherein the second attachment member comprises a prosthetic pylon attachment plate for attaching the second joint structure to the prosthetic pylon.

16. The prosthetic walking system of claim 12 wherein one of the joint structures includes a plate lying in a transverse plane, the plate having a v-shaped notch extending forwardly from a rear transverse edge of the plate, and wherein the other of the joint structures includes a restraining member projecting into the notch so that plantar flexal pivotal movement causes the restraining member to move into a narrower portion of the notch whereby the ankle joint is progressively stabilized in the coronal plane as the ankle joint progressively pivots in the plantar flexal direction.

17. A prosthetic walking system, comprising:

a prosthetic pylon;

a prosthetic foot;

a prosthetic ankle joint connecting the prosthetic pylon to the prosthetic foot, the ankle joint, comprising:

a first joint structure attachable to one of either the prosthetic pylon or the prosthetic foot;

a second joint structure attachable to the other of either the pylon or the prosthetic foot;

a bearing interconnecting the first joint structure and the second joint structure so that the first and second joint structures can pivot about a pivot axis in dorsiflexion and plantar flexion;

a dorsiflexion cushion positioned between the first and second joint structures at a first location causing the dorsiflexion cushion to be compressed during dorsiflexal pivotal movement of the ankle joint, the first location being spaced from the pivot axis by a first distance; and

a plantar flexion cushion positioned between the first and second joint structures at a second location causing the plantar flexion cushion to be compressed during plantar flexal pivotal movement of the ankle joint, the second location being spaced from the pivot axis by a second distance that is different from the first distance so that the torsional spring constant of the prosthetic ankle in dorsiflexion may be different from the torsional spring constant of the prosthetic ankle in plantar flexion using the same material for the dorsiflexion and plantar flexion cushions; the pivot point of the spherical bearing being offset in either a forward or a rearward direction past the first and second locations so that a compressive force applied between the first and second locations imparts a dorsiflexal torque about the pivot axis whereby the dorsiflexion cushion is compressed by both dorsiflexal pivotal movement between the first and second joint structures and by linear movement between the first and second joint structures toward each other.

18. The prosthetic walking system of claim 17 wherein the bearing is a spherical bearing allowing coronal rotational and transverse rotational pivotal movement of the ankle joint as well as dorsiflexal and plantar flexal pivotal movement of the ankle joint.

19. The prosthetic walking system of claim 17 wherein the first attachment member comprises a prosthetic foot attachment plate for attaching the first joint structure to the prosthetic foot, and wherein the second attachment member comprises a prosthetic pylon attachment plate for attaching the second joint structure to the prosthetic pylon.

20. The prosthetic walking system of claim 17 wherein one of the joint structures includes a plate lying in a transverse plane, the plate having a v-shaped notch extending forwardly from a rear transverse edge of the plate, and wherein the other of the joint structures includes a restraining member projecting into the notch so that plantar flexal pivotal movement causes the restraining member to move into a narrower portion of the notch whereby the ankle joint is progressively stabilized in the coronal plane as the ankle joint progressively pivots in the plantar flexal direction.

21. A prosthetic walking system comprising:

a prosthetic pylon;

a prosthetic foot;

a prosthetic ankle joint connecting the prosthetic pylon to the prosthetic foot, the ankle joint, comprising:

a first joint structure attachable to one of either a pylon or a prosthetic foot;

a second joint structure attachable to the other of either a pylon or a prosthetic foot;

a dorsiflexion cushion positioned between the first and second joint structures at a first location causing the dorsiflexion cushion to be compressed during dorsiflexal pivotal movement of the ankle joint, the dorsiflexion cushion having a dorsiflexion cushion thickness in the direction it is compressed;

a plantar flexion cushion positioned between the first and second joint structures at a second location causing the plantar flexion cushion to be compressed during plantar flexal pivotal movement of the ankle joint, the plantar flexion cushion having a plantar flexion cushion thickness in the direction it is compressed;

a bearing pivotally interconnecting the first joint structure and the second joint structure so that the first and second joint structures can pivot about a pivot axis in dorsiflexion and plantar flexion, the pivot point of the bearing being offset in a rearward direction so that a compressive force applied between the first and second locations imparts a dorsiflexal torque about the pivot axis whereby the dorsiflexion cushion is compressed by both dorsiflexal pivotal movement between the first and second joint structures and by linear movement between the first and second joint structures toward each other; and

a stop cushion positioned between the first and second joint structures at a location causing the stop cushion to be compressed during one of either dorsiflexal pivotal movement or plantar flexal pivotal movement and having a stop cushion thickness in the direction the stop cushion is compressed which is less than one of either the dorsiflexion cushion thickness or the plantar flexion cushion thickness, respectively, so that the torsional spring constant of the prosthetic ankle in one of either dorsiflexion or plantar flexion, respectively, is greater when the stop cushion is compressed than when the stop cushion is not compressed.

22. A prosthetic walking system comprising:

a prosthetic pylon;

a prosthetic foot;

a prosthetic ankle joint connecting the prosthetic pylon to the prosthetic foot, the ankle joint, comprising:

a first joint structure attachable to one of either a pylon or a prosthetic foot;

a second joint structure attachable to the other of either a pylon or a prosthetic foot, one of the joint structures including a plate lying in a transverse plane, the plate having a v-shaped notch extending forwardly from a rear transverse edge of the plate, and wherein the other of the joint structures includes a restraining member projecting into the notch so that plantar flexal pivotal movement causes the restraining member to move into a narrower portion of the notch whereby the ankle joint is progressively stabilized in the coronal plane as the ankle joint progressively pivots in the plantar flexal direction;

a bearing pivotally interconnecting the first joint structure and the second joint structure so that the first and second joint structures can pivot about a pivot axis in dorsiflexion and plantar flexion;

a dorsiflexion cushion positioned between the first and second joint structures at a first location causing the dorsiflexion cushion to be compressed during dorsiflexal pivotal movement of the ankle joint, the dorsiflexion cushion having a dorsiflexion cushion thickness in the direction it is compressed;

a plantar flexion cushion positioned between the first and second joint structures at a second location causing the plantar flexion cushion to be compressed during plantar flexal pivotal movement of the ankle joint, the plantar flexion cushion having a plantar flexion cushion thickness in the direction it is compressed; and

a stop cushion positioned between the first and second joint structures at a location causing the stop cushion to be compressed during one of either dorsiflexal pivotal movement or plantar flexal pivotal movement and having a stop cushion thickness in the direction the stop cushion is compressed which is less than one of either the dorsiflexion cushion thickness or the plantar flexion cushion thickness, respectively, so that the torsional spring constant of the prosthetic ankle in one of either dorsiflexion or plantar flexion, respectively, is greater when the stop cushion is compressed than when the stop cushion is not compressed.

23. A prosthetic walking system comprising:

a prosthetic pylon;

a prosthetic foot;

a prosthetic ankle joint connecting the prosthetic pylon to the prosthetic foot, the ankle joint, comprising:

a first joint structure attachable to one of either a pylon or a prosthetic foot;

a second joint structure attachable to the other of either a pylon or a prosthetic foot;

a dorsiflexion cushion positioned between the first and second joint structures at a first location causing the dorsiflexion cushion to be compressed during dorsiflexal pivotal movement of the ankle joint, the dorsiflexion cushion having a dorsiflexion cushion thickness in the direction it is compressed;

a plantar flexion cushion positioned between the first and second joint structures at a second location causing the plantar flexion cushion to be compressed during plantar flexal pivotal movement of the ankle joint, the plantar flexion cushion having a plantar flexion cushion thickness in the direction it is compressed;

a stop cushion positioned between the first and second joint structures at a location causing the stop cushion to be compressed during one of either dorsiflexal pivotal movement or plantar flexal pivotal movement and having a stop cushion thickness in the direction the stop cushion is compressed which is less than one of either the dorsiflexion cushion thickness or the plantar flexion cushion thickness, respectively, so that the torsional spring constant of the prosthetic ankle in one of either dorsiflexion or plantar flexion, respectively, is greater when the stop cushion is compressed than when the stop cushion is not compressed; and

a bearing pivotally interconnecting the first joint structure and the second joint structure so that the first and second joint structures can pivot about a pivot axis in dorsiflexion and plantar flexion, the pivot point of the bearing being offset in a rearward direction past the first and second locations so that a compressive force applied between the first and second locations imparts a dorsiflexal torque about the pivot axis where by the dorsiflexion cushion is compressed by both dorsiflexal pivotal movement between the first and second joint structures and by linear movement between the first and second joint structures toward each other.

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[54] PROSTHETIC FOOD AND THREE-WAY ANKLE JOINT

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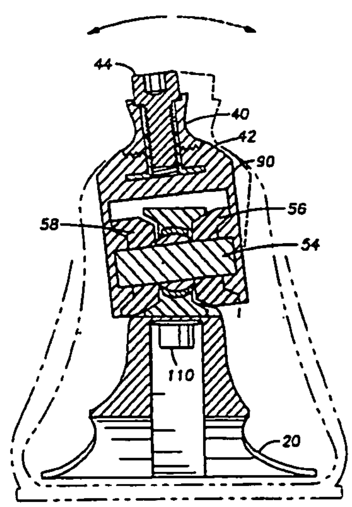
Primary Examiner—David H. Willse

Attorney, Agent, or Firm—Marcella D. Watkins

[57] ABSTRACT

A lightweight foot prosthesis is claimed, having a heel, a toe, and a raised instep, the instep including an upper surface and a lower surface, an ankle joint connected to the foot and capable of motion around each of three perpendicular axes, a pair of compression mounts for limiting rotation of the ankle joint, and a connector for connecting the ankle joint to a leg.

11 Claims, 9 Drawing Sheets



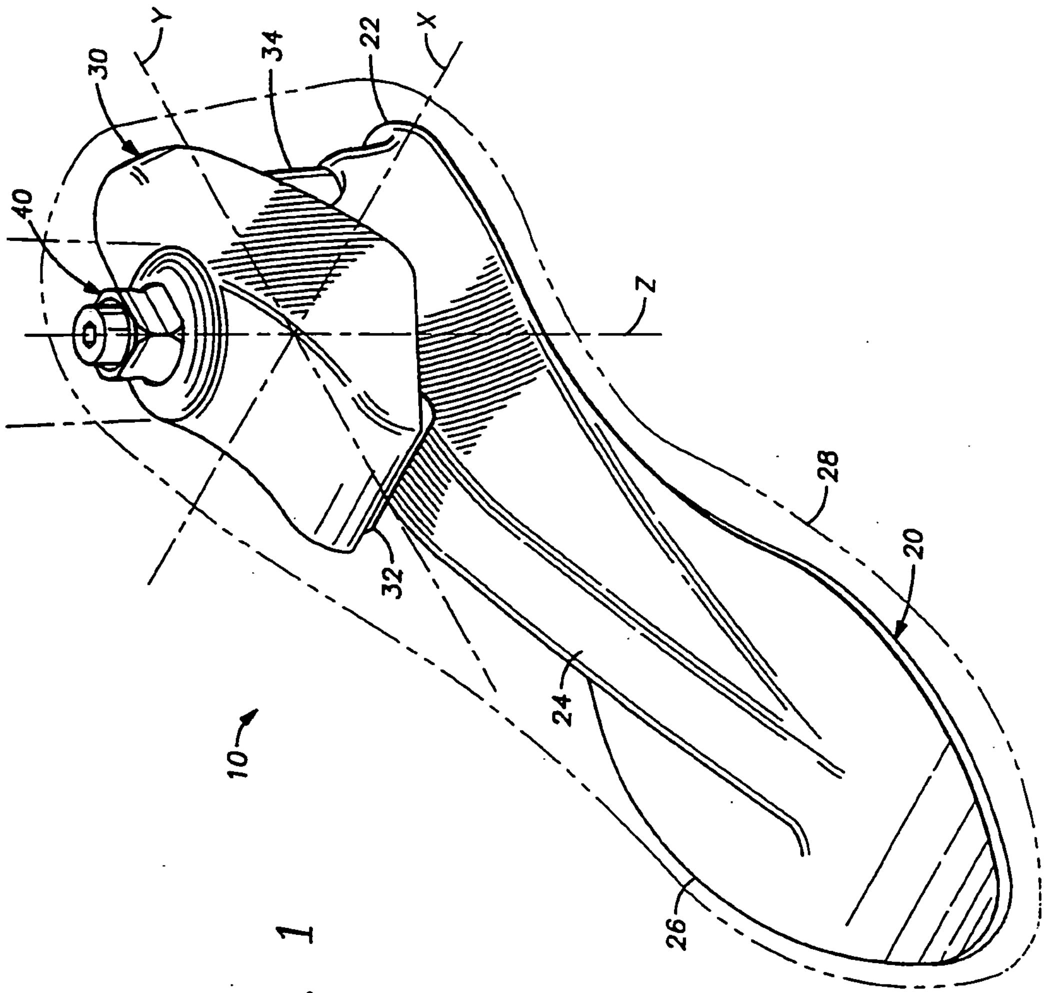


FIG. 1

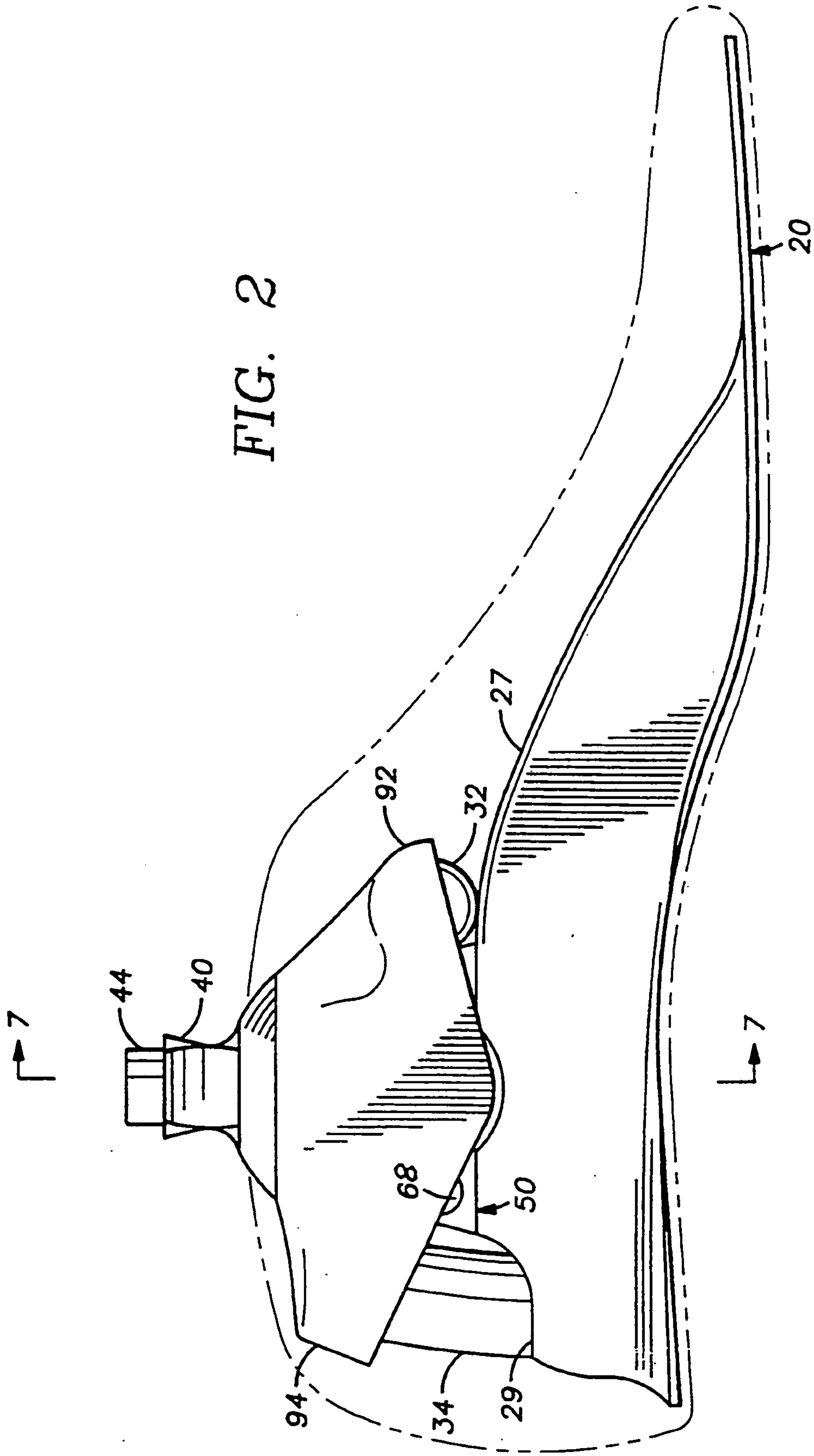


FIG. 2

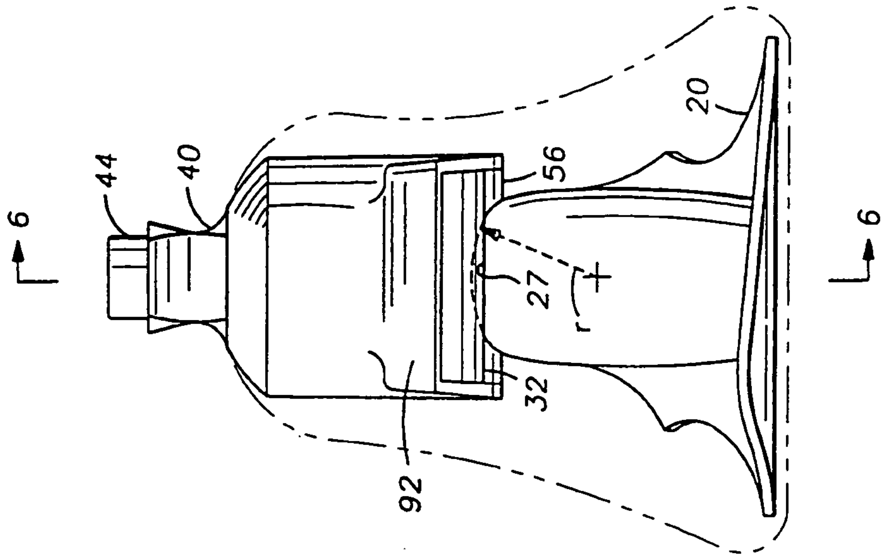


FIG. 4

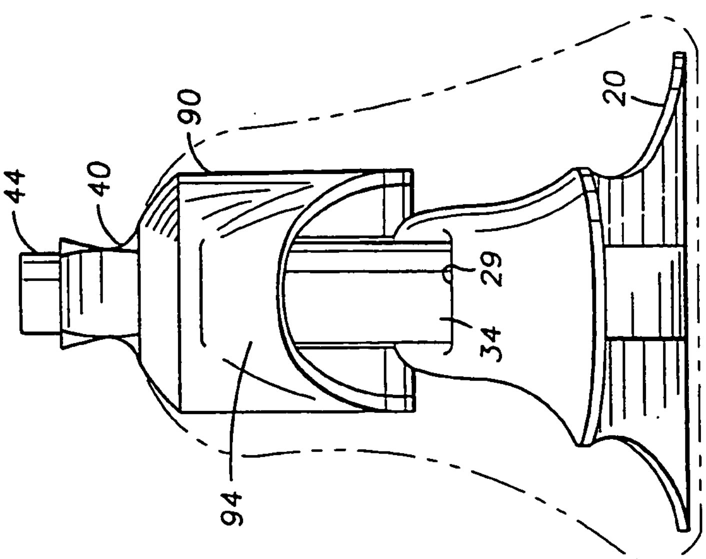


FIG. 3

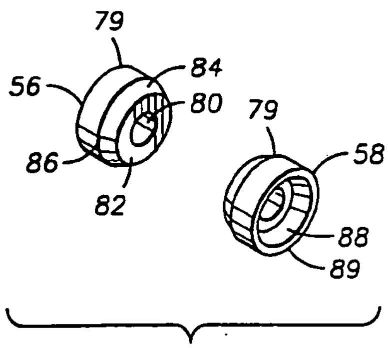


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FIG. 5A

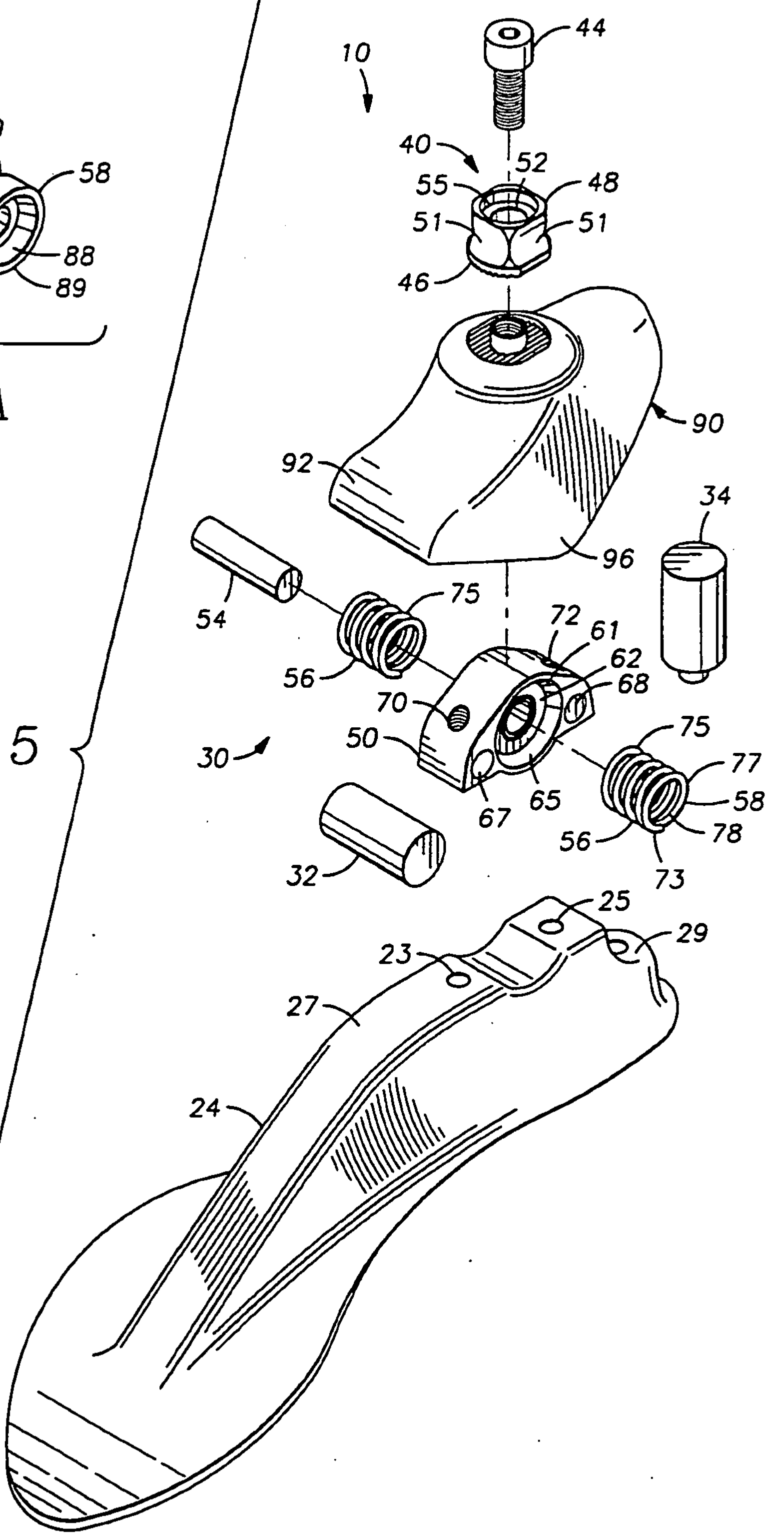

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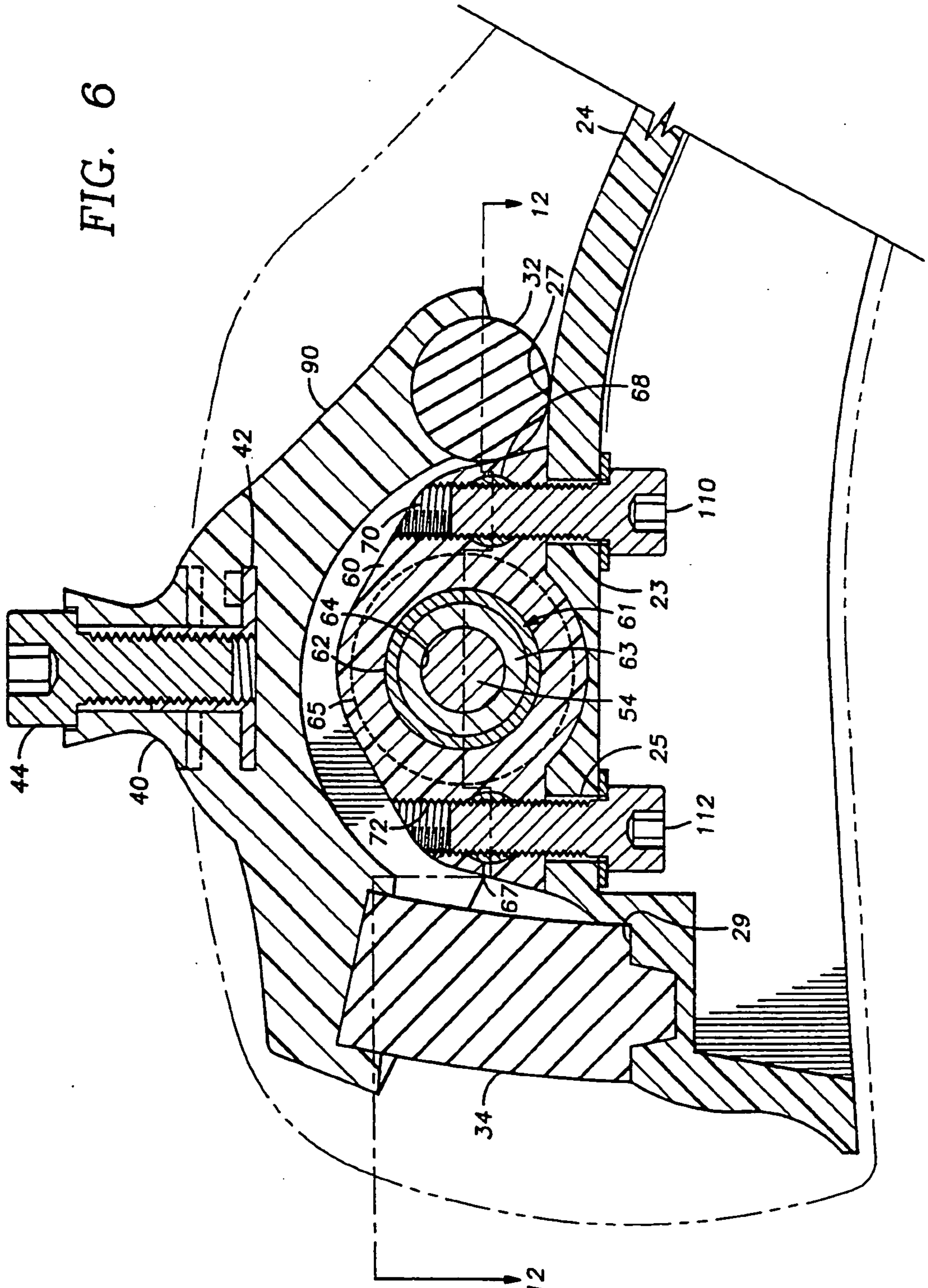
FIG. 5

FIG. 6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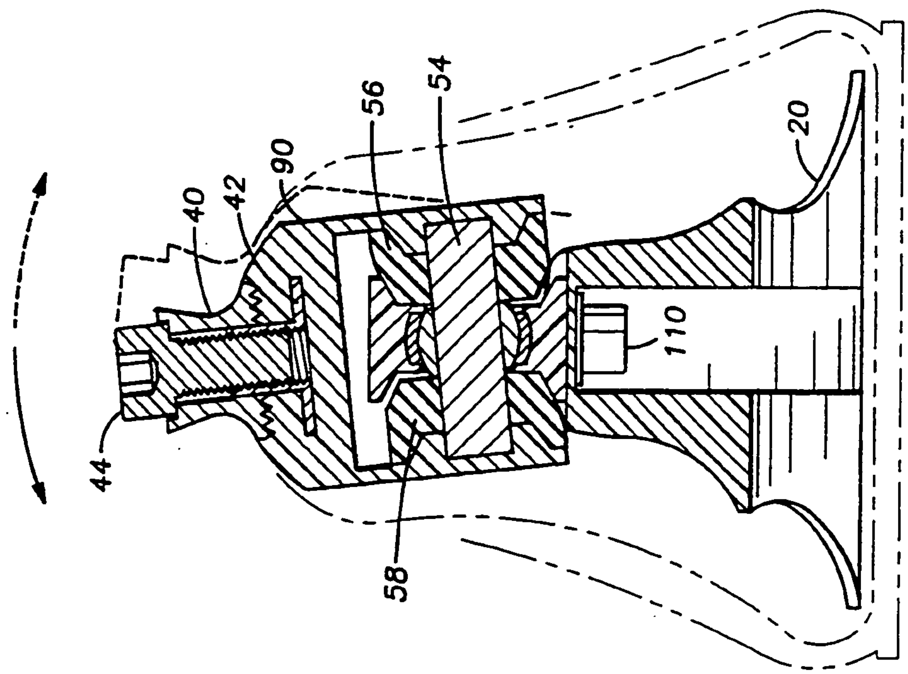
44
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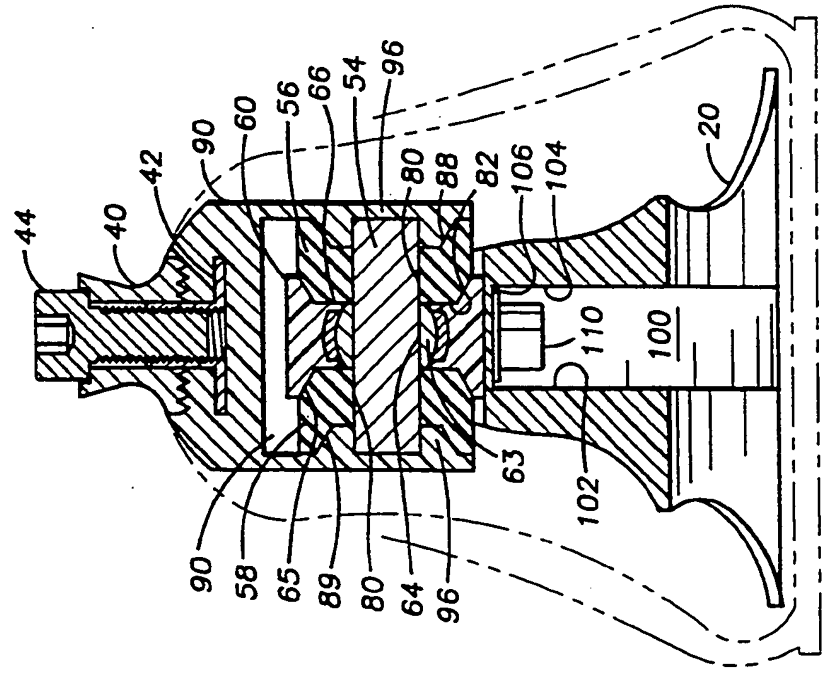
FIG. 11


44
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89
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FIG. 7

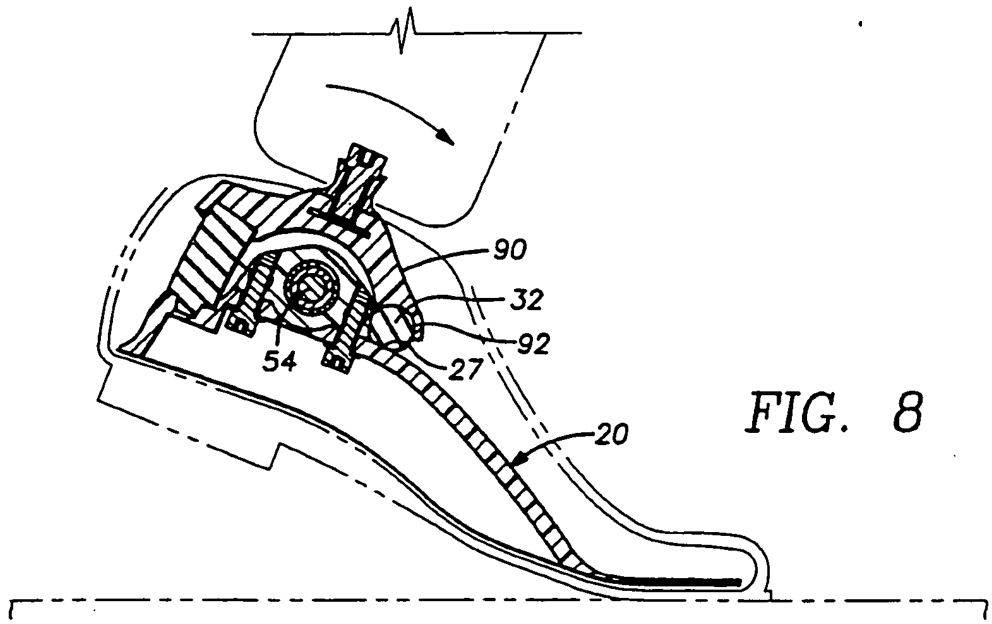

FIG. 8

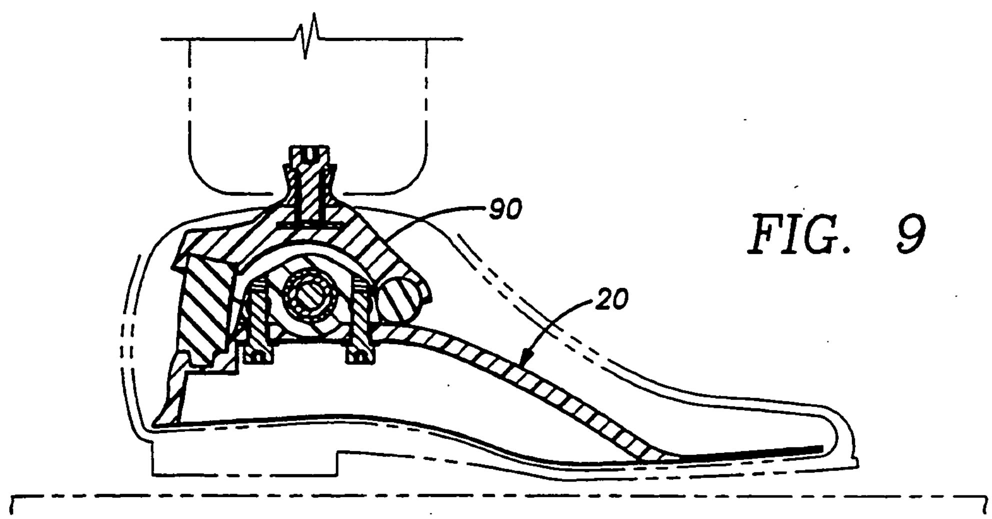

FIG. 9

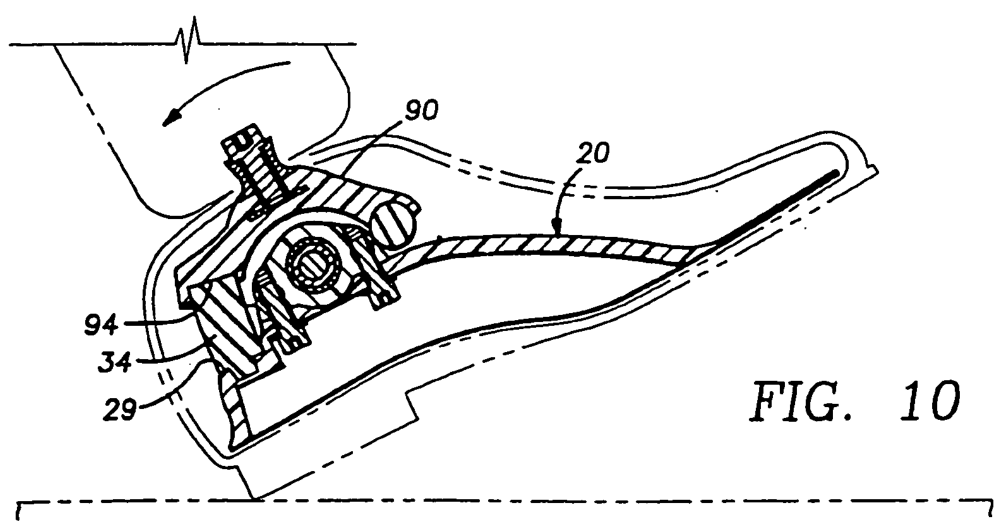

FIG. 10

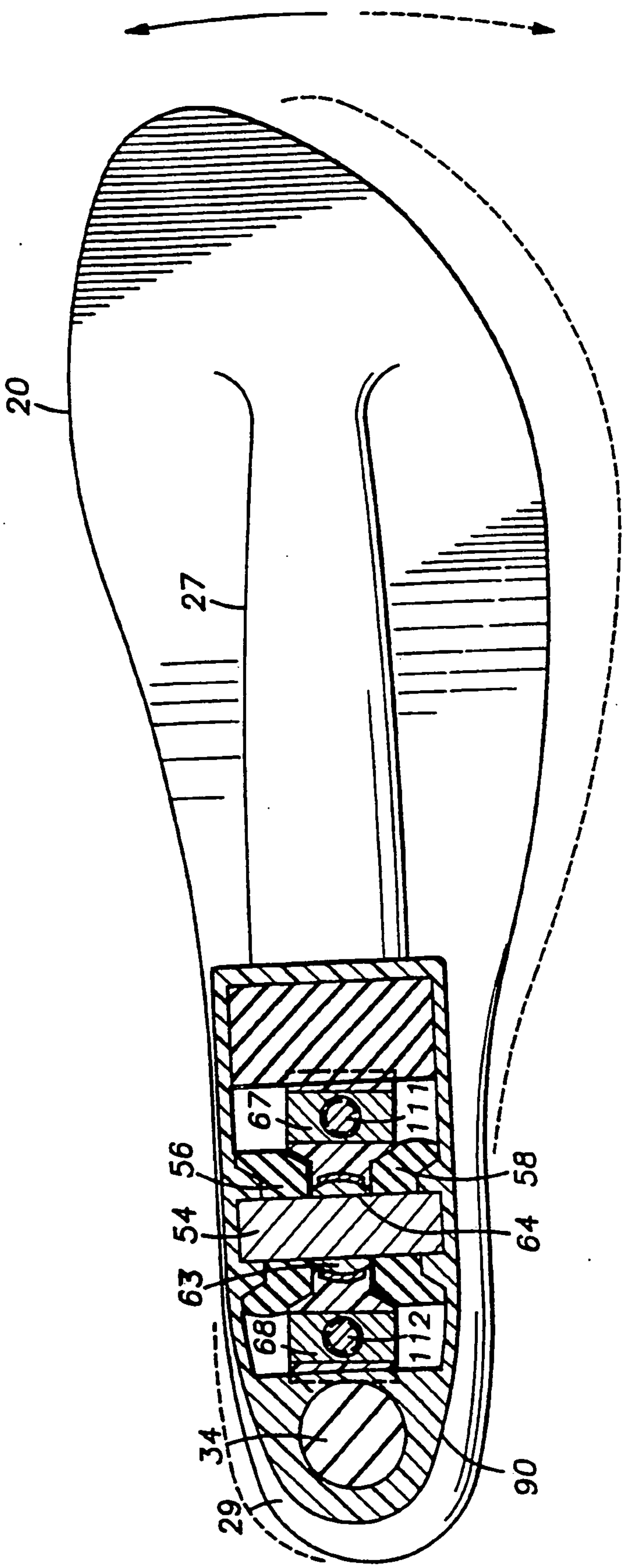

FIG. 12

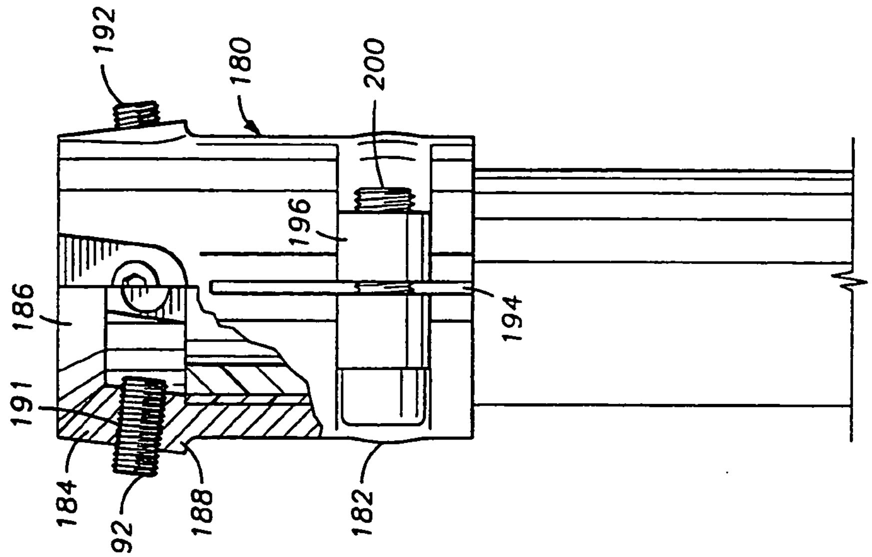

FIG. 15

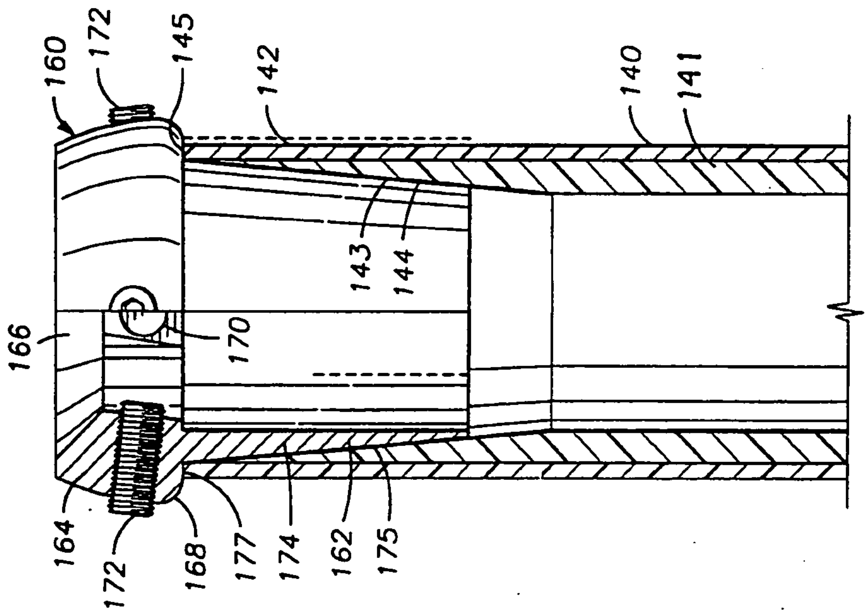

FIG. 14

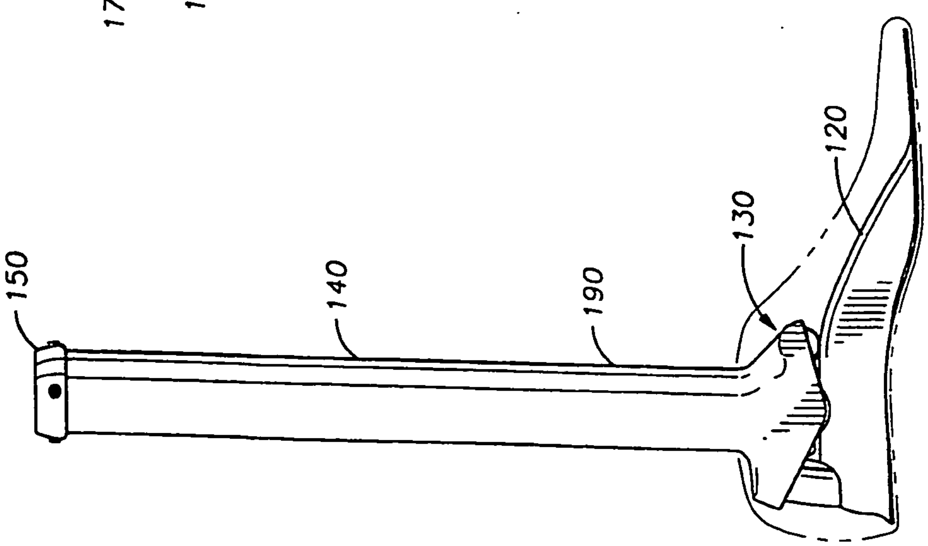

FIG. 13

PROSTHETIC FOOD AND THREE-WAY ANKLE JOINT

TECHNICAL FIELD OF THE INVENTION

The present invention relates to the foot section of an artificial leg and more particularly to a prosthetic foot specifically designed for geriatric users and others who require less massive prostheses. Still more particularly, the present invention relates to construction of a prosthetic foot and ankle joint adapted to provide a desired degree of mobility without excessive bulk.

BACKGROUND OF THE INVENTION

Prosthetic feet are well known in the art, and several such feet have been designed to accomplish one or more objectives.

A useful prosthesis must simulate the operation and motion of an anatomical foot. An anatomical foot, including the ankle joint, is capable of motion around three perpendicular axes, as well as varying degrees of flexure. Specifically, the anatomical foot and ankle are capable of dorsiflexion, planiflexion, inversion, eversion, and transverse rotation. Dorsiflexion and planiflexion comprise the movement up and down of the ball of the foot with respect to the heel that occurs during a normal forward step. Inversion and eversion are the twisting of the foot around its longitudinal axis, resulting in outward and inward tilting of the ankles, respectively. Transverse rotation occurs when the foot rotates with respect to the longitudinal axis of the leg, such as occurs during left and right turns of the body.

Known foot prostheses include commercial feet that are capable of all three types of rotation. Typically, however, the joints capable of such complicated motion require bulky moving parts and are generally far too heavy for geriatric or very young patients, or other patients who suffer some degree of muscular weakness.

In addition, it is desirable for a foot prosthesis to be capable of absorbing, storing, and releasing energy, so that the prosthesis returns itself to a relaxed, unflexed position when the moving force is removed. Prostheses that are designed for use during athletic activities, such as running or playing basketball, are particularly efficient at energy storage and return, providing a springy step. Such energy storage is typically accomplished by the inclusion of coil springs or other reciprocating means which absorb energy on flexure and release it efficiently upon removal of the applied force. The energy-storing components that are typically used for efficient return can contribute significantly to the weight of the prosthesis.

In contrast, older, less mobile wearers neither need nor want a high degree of return of stored energy. Instead, it is preferable for the prostheses worn by these wearers to absorb and dissipate a portion of the energy of each flexion. This provides a more stable, cushioned step, and reduces the shock experienced by both the wearer and the prosthesis at each step.

Finally, it is necessary that a foot prosthesis be strong enough to support its wearer and durable enough to withstand the stresses of repeated stepping motions over long periods of time. Conventional prostheses tend to be designed for maximized strength, at the cost of added bulk and weight, making them unsuitable for geriatric or very young wearers, who do not subject their prostheses to the same loads as the average wearer.

Hence it is desired to provide a flexible, durable prosthesis that provides a slightly damped step and requires a minimal mass.

SUMMARY OF THE INVENTION

The present invention comprises a foot prosthesis having a light-weight foot portion and an attached light-weight ankle portion capable of a desired degree of rotation around each of three perpendicular axes. As used herein, the words "prosthesis" or "foot prosthesis" will refer to both the foot portion of a prosthetic foot and the ankle joint attached thereto.

Simplified construction of the foot and joint mechanism enables the present invention to be at least about 50% lighter than typical foot prostheses. The foot portion includes an integral instep and sole constructed of light weight polymeric material and is designed to provide support and flexure without added weight. The ankle portion includes a single swivel joint that provides the desired flexibility and stability without excessive mass. Other objects and advantages of the present invention will appear from the following description.

BRIEF DESCRIPTION OF THE DRAWINGS

For a detailed description of a preferred embodiment of the invention, reference will now be made to the accompanying drawings wherein:

FIG. 1 is a perspective view of the prosthetic foot of the present invention wherein the surrounding cosmesis is shown in phantom;

FIG. 2 is a side elevational view of the prosthetic foot of FIG. 1;

FIG. 3 is a rear elevational view of the prosthetic foot of FIG. 1;

FIG. 4 is a front elevational view of the prosthetic foot of FIG. 1;

FIG. 5 is an exploded view of the prosthetic foot of FIG. 1 without the cosmesis;

FIG. 5A is a perspective view of an alternate embodiment of two components shown in FIG. 5;

FIG. 6 is a cross-sectional view taken along lines 6—6 of FIG. 4;

FIG. 7 is a cross-sectional view taken along lines 7—7 of FIG. 2;

FIGS. 8–10 are sequential side elevational views of the foot of FIG. 1 showing motion of the foot and attached ankle joint through a step;

FIG. 11 is a rear elevational view of the prosthetic foot of FIG. 1 showing inversion of the ankle joint, with eversion of the same joint shown in phantom;

FIG. 12 is a cross-sectional, top view of the foot of FIG. 1 showing left transverse rotation, with right transverse rotation shown in phantom;

FIG. 13 is a side elevational view of a second embodiment;

FIG. 14 is a partially cut away elevation of a connector affixed to the top of the embodiment of FIG. 13; and

FIG. 15 is a partially cut away elevation of an alternative connector affixed to the top of the embodiment of FIG. 13.

DETAILED DESCRIPTION OF THE INVENTION

The present invention comprises a lightweight foot prosthesis, an ankle joint affixed to said foot, said foot capable of motion around each of three perpendicular

axes, means for limiting rotation of said ankle joint and means for connecting said ankle joint to a leg. The foot portion includes a foot having a dorsal surface and a plantar surface and comprising a heel, a toe and a raised instep.

Referring initially to FIGS. 1–4, the prosthetic foot 10 of the present invention includes a foot 20, an attached ankle joint 30, and a connector 40. A prosthetic shin, or leg, which would normally be attached to connector 40 via a conventional connection is shown in phantom. For purposes of discussion, the x, y, and z axes, about which the foot is designed to rotate, are shown and have been assigned as follows. The x axis is perpendicular to both the leg and foot, passing through the sides of the ankle. The y axis is perpendicular to the leg and parallel to the foot, and the z axis is parallel to the leg.

Still referring to FIGS. 1–4, foot 20 comprises a heel 22, a raised instep 24, and a substantially flat toe portion 26. Together, the heel, instep and toe 22, 24, 26 form a foot that closely replicates the structure and form of an anatomical foot. FIG. 1 also shows in phantom a cosmesis 28, which is molded around prosthetic foot 10. Cosmesis 28 is preferably constructed of foamed polyethylene.

It is preferred that the x axis, which passes through joint 30, be approximately twenty-five percent (25%) of the distance from heel 22 to toe 26. In addition, it is preferred that the transition from instep 24 to toe 26 occur at approximately seventy-five percent (75%) of the distance from heel 22 to toe 26.

Foot portion 20 is preferably constructed of a molded copolymer comprising approximately 90% polypropylene and approximately 10% polyethylene. It has been found that this copolymer combines heat formability with a desired degree of strength and impact resistance. Other materials having these desired physical properties may be substituted for these polymers without departing from the spirit of the invention. Foot portion 20 is formed by molding a working piece of the copolymer around a rigid model having a desired shape. It has been found advantageous to at least partially evacuate a region adjacent to the model. This allows the surrounding atmosphere outside the working piece to apply isostatic pressure to the piece, thereby causing it to conform smoothly and completely to the form. Alternatively foot portion 20 may be injection molded. For lightness, the molded underside (not shown) of raised instep 24 may include a hollow recess, as discussed in greater detail below.

A forward snubber 32 and a rear snubber 34 are interposed between foot portion 20 and ankle joint 30 as discussed in greater detail below. Snubbers 32 and 34 comprise cylindrical resilient members and are preferably constructed of rubber, neoprene, high density urethane, or the like. A preferred material for the construction of snubbers 32, 34 is a polyurethane sold under the registered trademark Flexane® and manufactured by ITW Devcon, 30 Endicott St., Danvers, Mass. 01923.

Referring now to FIG. 5, the components of prosthesis 10 are shown in exploded form. Instep 24 includes a forward bore 23 and a rear bore 25 therethrough. Instep 24 includes a curved front contact surface 27 and a planar rear contact surface 29 on its upper, or dorsal surface. As best shown in FIG. 4, contact surface 27 has a radius of curvature r. Ankle joint 30 comprises a body 50, a shaft 54, a pair of compression mounts 56, 58, and a shell 90. Shell 90 includes a forward cup 92, a rear cup 94 and a pair of side portions 96. Shell 90 houses body 50, shaft 54 and compression mounts 56, 58 as described in detail below.

As best shown in FIGS. 6–7, body 50 includes an oblong housing 60 in which a swivel joint 61 is transversely mounted. Swivel joint 61 includes an outer race 62 (shown in phantom). Outer race 62 supports an inner race 63. Inner race 63 is rotatable within outer race 62 and has a central bore 64 therethrough. Bore 64 is adapted to receive shaft 54, such that shaft 54 lies on the x axis. Such swivel joints are commonly available, one being manufactured by Boston Gear, a subsidiary of Incom International, Inc. of Quincy, Mass.

Shaft 54 must be capable of withstanding significant shear stresses. Therefore, it is preferable that shaft 54 be constructed of hardened steel. Specifically, commercially available roll pins have been found suitable for use as shaft 54.

Still referring to FIGS. 6 and 7, each side face of housing 60 includes an annular bevel 65 centered on swivel joint 61. Bevel 65 forms an annular seating face 66. Parallel to and proximate swivel joint 61 are a forward transverse support 67 and a rear transverse support 68. A pair of vertical bores 70, 72 pass through body 50, intersecting transverse supports 67 and 68, respectively. For structural purposes, it is desired that the diameter of supports 67, 68 exceed the diameter of bores 70, 72. This ensures that a portion of each support extends beyond the bore, as shown.

According to the preferred embodiment, housing 60 is formed by winding unidirectional glass fiber circumferentially around the outer race 62 of swivel joint 61, and continuing the winding around and adjacently positioned transverse supports 67, 68 to form the oblong housing shape. The glass fiber is then impregnated with an epoxy, to form a rigid, durable body.

Referring again to FIG. 5, compression mounts 56 and 58 preferably comprise identical cylindrical coil springs 75, each having an inner end 76, an outer end 77 and a coaxial opening 78. Inner ends 76 are sized and shaped to receive the ends of shaft 54, and are sized to seat on seating face 66 within bevel 65 of housing 60. In an alternate embodiment, outer ends 77 may have a slightly larger diameter than inner ends 76.

According to a second alternate embodiment, shown in FIG. 5A, each compression mount 56, 58 comprises a solid resilient annulus 79 having a central bore 80 therethrough. Central bore 80 corresponds to opening 78 of the preferred embodiment and is sized to receive shaft 54. The inner face 82 of each annulus 79 is substantially flat and is sized to rest on seating face 66. Adjacent inner face 82 is a bevel 84 which extends to outer circumference 86 and corresponds to bevel 65. The outer face of each annulus 79 comprises a concave face 88 and an adjacent circumferential lip 89. In this second embodiment, annuli 79 are preferably molded of a tough, resilient material, such as rubber, neoprene, high density urethane, or the like. As with snubbers 32, 34, discussed above, a preferred material for the construction of resilient compression mounts 56 , 58 is Flexane® manufactured by Devcon, see address above.

Still referring to FIG. 5, connector 40 is affixed to shell 90 by means of a T-nut 42 and a bolt 44. Connector 40 comprises an annular flange 46 adjacent one end of a coaxial four-sided body 48. The lower face of flange 46 preferably includes a plurality of longitudinal grooves 49 that run from the front to the back of the flange. Body 48 includes four curved faces 51 and a central

bore 52 therethrough. Surrounding bore 52 is a recess 55, which is adapted to receive the head of bolt 44. T-nut 42 comprises an internally threaded body 57 and an adjacent flange 58, which supports four locking tabs 59 (not shown). Preferably, T-nut 42, connector 40 and bolt 44 are made of metal and most preferably of steel.

Connector 40 is the male component of a standard adjustable connection formerly manufactured by the Otto Boch Corp. of West Germany and now widely available. Because of its strength and adjustability, this type of connection is presently used for virtually every non-flexible prosthetic connection.

Referring again to FIG. 7, the relation of shell 90 to connector 40, body 60, shaft 54, compression mounts 56, 58 and foot 20 is shown. When ankle joint 30 is assembled, shaft 54 passes through bore 64 of inner race 63 and through coaxial openings 78 of compression mounts 56, 58. Inner faces 82 rest on seating faces 66 so that the ends of shaft 54 extend through concave faces 88. Shell 90 is constructed so that side portions 96 of shell 90 extend over and encase the ends of shaft 54, forming a permanent connection. In surrounding the ends of shaft 54, the material of side portions 96 is received within the concave faces 88 of compression mounts 56, 58. Between shell 90 and the top of body 60 is a void 98. T-nut 42 is molded into the top of shell 90.

To affix connector 40 to shell 90, connector 40 is seated on T-nut 42 so that the grooves in flange 46 seat in corresponding grooves in shell 90 and prevent connector 40 from shifting laterally with respect to shell 90. Bolt 44 passes through connector 40 and threadingly engages T-nut 42.

Still referring to FIG. 7, instep 24 of foot 20 includes a lower recess 100. Preferably, recess 100 comprises a longitudinal groove in instep 24 having side walls 102, 104 and an inner wall 106. As shown in FIGS. 5 and 4, inner wall 106 includes a pair of bores 23, 25.

According to a preferred embodiment, shell 90 is constructed around connector 40, body 60, shaft 54, compression mounts 56, 58 in a series of steps that result in a strong but relatively light joint. First, shaft 54 is placed through inner race 63 and compression mounts 56, 58 are placed over the ends of shaft 54 and seated against body 60. If springs 75 are used as compression mounts, a conical liner (not shown) is placed within the outer end 77 of each spring, to prevent the flow of epoxy into the spaces between the coils of the spring.

Next, a wax cast is molded around these assembled components. The outer surface of the wax cast is sculpted to correspond to the desired contours of the inner surface of shell 90, including the seats for snubbers 32, 34 in forward and rear cups 92, 94, and the outer contours of void 98. The dorsal surface of the wax cast is then wrapped in fiberglass. Preferably the fiberglass includes the following layers:

Position	No. of Layers	Weight of Fiber	Type of Glass	Orientation
1	1	6 oz.	bidirectional	front to rear
2	1	13 oz.	unidirectional	front to rear
3	2	6 oz.	bidirectional	side to side
4	2	26 oz.	unidirectional	side to side
5	2	26 oz.	unidirectional	front to rear*
6	1	26 oz.	unidirectional	transverse**

-continued

Position	No. of Layers	Weight of Fiber	Type of Glass	Orientation
7	N/A	52 oz.	mat	N/A***

*One layer ends in front of T-nut 42 and one passes over T-nut 44.
**This layer extends only across the front end 92 of shell 90.
***Glass mat is shaped to form the dome of joint 30, which serves to restrain T-nut 42 and provide support for a prosthetic leg connection.

Once all of the desired layers of fiberglass have been assembled around the wax cast,.the wrapped cast is inserted into a mold, which is then sealed. The mold corresponds to the desired outer surface of shell 90, and includes grooves 99 running from front to back along the uppermost surface. Grooves 99 in shell 90 correspond to the grooves in flange 46 of connector 40. Epoxy is drawn into the void between the cast and the mold, thoroughly impregnating the fibers. Once the shell has been thus formed, the joint is removed from the mold. The wax is melted and removed, leaving the joint shown in FIG. 3 and described above.

By positioning the connection of shell 90 to shaft 55 at least partially within compression mounts 56, 58, the present design allows ankle joint 30 to be narrower along the x axis than it would otherwise be. The narrow shape substantially reduces the weight of the joint and makes it easier for the completed joint to be removed from the mold.

It has been found advantageous to provide ankle joint 30 in a plurality of sizes. Specifically, it has been found that three sizes are adequate to support the normal range of necessary prosthesis sizes. The size of swivel joint 61 varies according to the desired prosthesis size. For example, for a large size prosthesis, central bore 64 of inner race 63 has a diameter of $\frac{3}{8}$ inches; a medium prosthesis has a bore of 5/16 inches, and a small prosthesis has a bore of $\frac{1}{4}$ inch. As mentioned above, shaft 54 is sized to be snugly received within bore 64. Hence, the size of shaft 54 also varies according to the joint size.

It is preferred that the height, or depth, of instep 24 be approximately 10–15 percent of the length of foot portion 20. This allows the cross-section across the y axis of instep 24 to be great enough to provide the necessary rigidity through the middle of the foot, while maintaining the x axis (through bore 64) as low as possible. Another advantage of this relation is that it allows the top and bottom molds for the cosmesis to be approximately equal in volume, making assembly of the prosthesis easier.

Referring now to FIGS. 6 and 7, ankle joint 30 is attached to foot 20 by means of a pair of bolts 110, 112. Bolts 110, 112 pass through bores 23, 25, respectively and engage bores 70, 72, respectively, in body 50. It will be understood that bolts 110, 112 could be replaced with a single bolt, or other suitable attachment means. It is believed advantageous, however, to use at least two such attachment means, as it reduces fatigue in the attachment, even if the attachment(s) develop slack.

When foot 20 is bolted to body 50, snubber 32 is positioned transversely within the forward cup 92 of shell 90 so that it rests on front contact surface 27. Snubber 32 is sized so that its diameter is approximately equal to the distance between contact surface 27 of instep 24 and the underside of forward cup 92 of shell 90. Because contact surface 27 is curved from side to side, only the center portion of forward snubber 32 contacts surface 27 in the normal, unflexed position.

Rear snubber 34 is positioned vertically within the rear cup 94 of shell 90 so that it rests on contact surface 29. Snubber 34 is sized so that its length is approximately equal to the distance between planar surface 29 of instep 24 and the underside of rear cup 94 of shell 90.

Referring now to FIG. 8, during dorsiflexion, the leg is inclined toward the front of the foot. Dorsiflexion occurs during the "push-off" phase of a normal step, or during uphill walking. In the prosthesis of the present invention, dorsiflexion causes a clockwise (as shown) moment about the x axis to be applied to shell 90. Because shell 90 is affixed to the ends of shaft 54, shaft 54 rotates within swivel mount 61 as shell 90 pivots. Pivoting of shell 90 causes front snubber 32 to be compressed between front contact surface 27 and forward cup 92. As the degree of flexion increases, snubber 32 deforms to fully contact the curved contact surface 27. Because snubber 32 is resilient and is substantially confined within forward cup 92, it resists compression and biases foot 20 away from forward cup 92. During normal use, a maximum dorsiflexion about shaft 54 of approximately 10 to 15 degrees will occur.

For a given prosthesis size, the degree of dorsiflexion that can occur depends in part on the durometer, or hardness, of forward snubber 32. A desired durometer can be selected by modifying the composition of the snubber material. Methods for altering the durometer of a material, and of polymers in general are well known. If, as discussed above, Flexane® is used, an additive marketed under the trademark Flex-Add TM and also manufactured by Devcon, may be used to produce a softer polymer.

The radius of curvature r of contact surface 27 also affects the resistance of joint 30 to dorsiflexion. The smaller the radius of curvature r of contact surface 27, the smaller the area is of surface 27 that contacts snubber 32. With a smaller area, greater pressure will be applied by a given force, causing greater deformation. A surface 27 having a smaller radius of curvature will distort snubber 32 to a greater degree and allow more degrees of dorsiflexion with the same force. Thus, the same effect can be achieved by providing either a softer snubber or a smaller radius of curvature for contact surface 27.

The height of instep 24 can also affect the dorsal flexibility of the prosthetic foot. Because the flexibility of an object depends on its cross-section in the direction of flexure, raising the height of instep 24 produces a stiffer foot. Likewise, a more flexible foot can be produced by decreasing the height of instep 24. Because foot 20 is made substantially of polypropylene in a preferred embodiment, it is capable of some flexure without breaking. As stated above, the height of instep 24 will approximately equal 10-15 percent of the length of foot 20.

In contrast to instep 24, toe portion 26 of foot 20 has a small cross-sectional area, and therefore flexes relatively easily. Hence, as the wearer's body mass moves forward over the foot and begins to straighten the ankle, the energy stored in front snubber 32 is transferred into flexure of toe portion 26. When the toe of prosthesis 10 leaves the ground, moment is removed from the joint and prosthesis 10 returns to its unflexed position as the leg swings forward, as shown in FIG. 9. It is preferred that joint 30 store only a minimum amount energy, that amount being the amount necessary to return the prosthesis to its unflexed position. It is preferred that excess energy be dissipated within the resilient components of joint 30, so as to avoid an excessively bouncy step. The degree to which energy is dissipated, rather than being released, can be controlled by modifying the composition and structure of the resilient components.

Referring now to FIG. 10, when the heel of prosthesis 10 is placed on the ground, a counter-clockwise moment is applied to the joint, resulting in planiflexion. As in dorsiflexion, shell 90 pivots, this time in a counter-clockwise direction about the x axis, causing shaft 43 to rotate in swivel joint 61. Rear snubber 34 is compressed between rear contact surface 29 of instep 24 and rear cup 94 of shell 90, and biases prosthesis 10 to return to an unflexed position. In addition, rear snubber 34 provides more shock-absorbing capability. Because it is oriented so that the compressive forces are applied along its longitudinal axis, it is capable of compression through a greater distance than the transversely mounted front snubber 32. During normal use, a maximum planiflexion about shaft 54 of approximately 10 to 30 degrees will occur. Once the foot is planted, as the wearer moves forward the moment is removed and prosthesis 10 returns to an unflexed position before commencing the next push-off phase as shown in FIG. 10.

Referring now to FIG. 11, the inversion of ankle 30 is shown. In FIG. 11, inversion results in counter-clockwise rotation of shell 90 with respect to foot 20 about the z axis. Eversion is shown in phantom. When ankle 30 inverts or everts while the foot is on the ground, a corresponding moment is applied to shell 90 via connector 40. The moment transmitted via shell 90 tends to force the two ends of shaft 54 in opposite directions. Shaft 54 passing through bore 64 causes inner race 63 to swivel within outer race 62. As shaft 54 swivels, each compression mount 56, 58 is compressed between side portions 96 of shell 90 and housing 60. Because mounts 56, 58 are resilient, they push against bevel 65 and seating face 66, and resist swiveling of shaft 54. Before compression mounts 56, 58 are fully compressed, body 50 reaches its maximum rotation within shell 90 and is prevented by shell 90 from rotating further. During normal use, a maximum rotation of approximately 10 degrees will occur before body 50 contacts shell 90. Because front contact surface 27 is curved, snubber 32 can tilt from side to side with shell 90 without interfering with inversion or eversion of the joint.

The force required to rotate any given joint depends on both the construction and configuration of compression mounts 56, 58. The deeper the conical liners used with springs 75 or the concave faces 88 of annuli 79 are, the more material of side portions 96 of shell 90 will flow into the voids between faces 88 and the ends of shaft 54. Because shell 90 is constructed of a rigid, incompressible material, whereas compression mounts 56, 58 are compressible, decreasing the flexibility of mounts 56, 58 and increasing the amount of shell material surrounding shaft 54 has the effect of limiting the ability of shaft 54 to swivel about the y and z axes. If there is too much space between mounts 56, 58 and the ends of shaft 54, too much material of side portions 96 will enter that space and will excessively reduce the degree of motion of which the joint is capable. Hence, the stiffness of swivel joint 61 with respect to transverse rotation can be controlled through the design of mounts 56, 58.

When prosthesis 10 is removed from the ground, the moment about the z axis is removed and the energy stored in mounts 56, 58 causes foot 20 to re-align itself with shell 90.

Left and right transverse rotation as shown in FIG. 12 are accomplished in the same manner as transverse rotation. That is, rotation of the ankle to either the left or right about the z axis, as shown in FIG. 10, results in a moment applied to shell 90. The moment is transmitted through side portions 96 to the ends of shaft 54. Shaft 54 causes inner race 63 to swivel within outer race 62. Compression mounts 56, 58 are again compressed between the ends of shaft 54 and bevel 65. The energy stored in compression mounts 56, 58 can be used to return prosthesis 10 to an unflexed position when the moment is removed. Transverse rotation occurs when the wearer changes direction and, to a lesser degree, during the cycle of each step, as the wearer's pelvis twists slightly from side to side. The ability of the present prosthesis to accommodate such transverse rotation and to yield more easily to smaller degrees of rotation enhances the comfort and stability of the prosthesis.

It will be understood that the prosthesis of the present invention is capable of rotation about two or more axes simultaneously. Within the mechanical limitations of swivel joint 61, rotation of the joint about any one axis has no effect on its rotation about the other two axes. An advantage of the joint of the present invention lies in the fact that it closely simulates the range of motion of an anatomical foot. Shaft 54 within inner race 63 allows a greater degree of flexure about the x axis than is allowed about either the y or z axes. This dissimilarity corresponds to the range of motion allowed by an anatomical ankle.

According to a second embodiment shown in FIG. 13, connector 40, T-nut 42, and bolt 44 may be eliminated and replaced with an integral prosthetic shin. In this embodiment, the lower leg and shell 90 are formed from a single molded piece of fiber glass. The elimination of the metal connection therebetween results in a desirable weight savings. The adjustability of the connection that is achieved by the connector 40 with its four curved attachment faces 51 is lost, but the integration of the lower leg with shell 90 can be customized to duplicate the optimal relation of the lower leg to shell 90 for each wearer.

Referring still to FIG. 13, this alternate prosthetic foot comprises a foot 120, an ankle joint 130, a lower leg 140, and a connector 150. Foot 120 and ankle 130 are virtually the same as foot 20 and ankle 30 described above and shown in FIGS. 1-12. A shell 190 encloses ankle joint 130 in the manner of shell 90 discussed above. Connector 150 may be either male or female, as is discussed in greater detail below.

In place of a connector 40 affixed to shell 90 as above, however, lower leg 140 is molded as a single piece that is integral with shell 190. Like shell 190, lower leg 140 comprises fiberglass impregnated with epoxy.

Lower leg 140 comprises a hollow tube, thereby ensuring maximum strength with minimum mass. Lower leg 140 is preferably formed during the shell molding steps described above. To form lower leg 140, a preformed tube 141 (shown in FIGS. 14-15) is positioned with one end adjacent to the wax cast described above. The preformed tube is preferably wrapped with one layer of 6 oz. unidirectional glass fiber and placed in a mold. The fiberglass layers in shell 190 are modified to include layers that form and support the rigid joint between lower leg 140 and shell 190, as well as lower leg 140 itself. When the lower leg and shell have been impregnated with epoxy, they are removed from the mold. The preformed tube remains a part of, and forms the inside diameter of, lower leg 140.

In a preferred embodiment, the preformed tube is constructed of a bi-directional glass fiber impregnated with epoxy, such as G-10 glass cloth epoxy sheet. G-10 is manufactured by Westinghouse, Norplex, Spalding, and other manufacturers of epoxy fiberglass, and is widely available. G-10 has the necessary strength and durability for the present application. Other lightweight materials having similar physical properties may be substituted for the G-10 without departing from the spirit of the invention.

Referring now to FIG. 14, the upper end 142 of lower leg 140 is affixed to a male connector 160. In the preferred embodiment, the inside diameter 143 of the upper end of lower leg 140 is tapered, gradually increasing until it approximately equals the outside diameter of inner tube 141. Preferably, the degree of taper is small, for example traversing the axis of leg 140 at an angle of approximately 4 degrees. This tapered portion forms a conical annular shoulder 144 and a flat annular shoulder 145.

Still according to a preferred embodiment, connector 160 comprises a male lower portion 162, a coaxial adjacent female upper portion 164, and a central bore 166. Upper portion 164 comprises a rounded, annular shoulder 168, having a plurality of evenly circumferentially spaced radial bores 170 therethrough. Bores 170 are internally threaded and sized to receive an equal number of set screws 172. Preferably, there are four bores 170, spaced 90 degrees apart around shoulder 168.

Lower portion 162 of connector 160 comprises a tube 174 having a tapered outside diameter 175. The degree of taper equals the degree of taper of the inside diameter of lower leg 140. The tapered portion of connector 160 forms a conical annular shoulder 176, which corresponds to annular shoulder 144 of lower leg 140. Annular shoulder 168 of connector 160 forms a flat annular surface 177, which corresponds to flat annular shoulder 145 of lower leg 140. Hence, when lower portion 162 of connector 160 is inserted into the upper end of lower leg 140, shoulder 176 seats on shoulder 144, and flat annular surface 177 seats on flat annular shoulder 145, thereby centering and mounting connector 160 within lower leg 140. In practice, cement is applied to the shoulder surfaces, so that connector 160 and lower leg 140 are permanently joined.

The configuration of connector 160, i.e., having four opposed set screws 172, allows it to receive and be rigidly affixed to a standard four-sided male connector, such as connector 40 shown in FIGS. 1 and 2. Such a connector would typically be used to attach a knee joint to the prosthetic lower leg.

As shown in FIG. 15, a female connector 180 may be used in place of connector 160. Connector 180 comprises a female lower portion 182 that receives upper end 142 of leg 140, a coaxial female upper portion 184, and a central bore 186 therethrough. Upper end 184 includes a plurality of circumferentially spaced built-up shoulders 188, each having an internally threaded bore. 191 therethrough. Bores 191 are sized to receive set screws 192.

The circumference of lower portion 182 includes a partial longitudinal gap 194. On either side of gap 194 is a bracket 196, extending perpendicular to the outside wall of lower portion 182. Brackets 196 include opposing bores 198 (not shown) therethrough, so that when a tightening means, such as a bolt 200, is inserted through

bores 198 and tightened, gap 194 closes and lower portion 182 tightens around the upper end of leg 140.

In operation, connector 180 is placed over the upper end 142 of lower leg 140, with lower leg 140 extending into central bore 186. Bolt 200 is tightened, causing the lower portion 182 of connector 180 to tighten around lower leg 140. In this manner connector 180 is affixed to lower leg 140. The upper portion 184 of connector 180 is adapted to receive a standard four-sided male connector, and operates in substantially the same manner with respect to the knee joint as does the upper portion 164 of connector 160, described above.

The difference between annular shoulder 168 of connector 160 and the four built-up portions 188 of connector 180 is a matter of weight and ease of machining. One skilled in the art will understand that there are several ways of housing and supporting the set screws and that the shin/knee connectors may be modified from the configurations described above without departing from the spirit of the invention.

While a preferred embodiment of the invention has been shown and described, modifications thereof can be made by one skilled in the art without departing from the spirit of the invention. For example, the precise shape of the components, the materials of which they are constructed, the degree of motion that is allowed in each direction, and other aspects of the invention can be changed without departing from the spirit of the invention.

What is claimed is:

1. A lightweight foot prosthesis, comprising:

an integral foot having a heel, a toe, and a raised instep, said instep including a dorsal surface and a plantar surface;

an ankle joint affixed to said foot and capable of motion around each of three perpendicular axes;

means for limiting rotation of said ankle joint; and

means for connecting said ankle joint to a leg;

said ankle joint comprising a body, a swivel means housed in said body, a shaft rotatably mounted in said swivel means, and means for transmitting a force from the leg to said shaft, said rotation limiting means being disposed between said shaft and said body;

said swivel means including a housing having a transverse main bore therethrough, an outer race fixed herein, and an inner race rotatably housed in said outer race, said inner race having a central bore therethrough, said bore being sized to receive said shaft;

said rotation limiting means comprising a pair of annular compression mounts; and

said housing including a pair of annular beveled seating faces, each such face centered on said main bore, each of said compression mounts being seated on one such face.

2. The foot prosthesis according to claim 1 wherein said foot comprises a molded copolymer.

3. The foot prosthesis according to claim 2 wherein said copolymer comprises approximately 90 percent polypropylene and approximately 10 percent polyethylene.

4. The foot prosthesis according to claim 1 wherein said instep includes a longitudinal groove adjacent said plantar surface.

5. The foot prosthesis according to claim 1 wherein said toe is substantially flat.

6. The foot prosthesis according to claim 1 wherein said compression mounts comprise a tough, resilient material.

7. The foot prosthesis according to claim 1 wherein said force transmitting means comprises a joint shell affixed to said shaft such that tilting of the shell causes said shaft to swivel within said swivel means.

8. The foot prosthesis according to claim 7 wherein said dorsal instep surface includes a forward planar surface and a rear planar surface, further including second and third rotation limiting means positioned between said forward and rear planar surfaces and said shell, respectively.

9. The foot prosthesis according to claim 8 wherein said second rotation limiting means includes a transversely mounted forward snubber.

10. The foot prosthesis according to claim 9 wherein said third rotation limiting means includes a vertically mounted rear snubber.

11. The foot prosthesis according to claim 1 wherein said connection means comprises a lower leg prosthesis integral with said force transmitting means.

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